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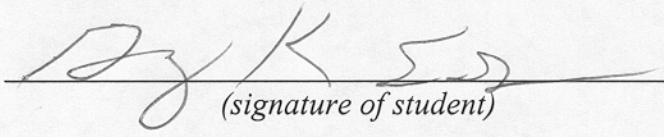
Agreed: 

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AN ASSESSMENT OF TICK DENSITY AND TICK-BORNE DISEASE FREQUENCY AT ARKANSAS POST NATIONAL MEMORIAL

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Forest Resources

by

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ABSTRACT

Concerns for visitor and employee safety, and documented cases of tick-borne disease at Arkansas Post National Memorial (ARPO), led to an assessment of tick density and the frequency and occurrence of Lyme Disease and Ehrlichiosis across vegetation types. Tick density was evaluated in 1999 and 2000 by life stage, season, and year for each vegetation type. Ticks were flagged in each vegetation type May through October for two years. Flagging is a method used to collect ticks. It uses either a drag or flag whereby vegetation is sampled either behind or before the researcher, respectively. All ticks were identified to species, sex, and life stage. A total of 44832 ticks were collected during the study representing three genera and six species. Of these, 99.6% consisted of lone star ticks (*Amblyomma americanum*). Tick abundance varied among and within vegetation types by season. Overall, adult and nymph tick abundance was highest in the spring, and larvae were highest in the summer and early fall, with a resurgence of adults in the late fall. Twelve vegetation types exist at the park, five of these, excluding the mowed areas, are considered high visitor use areas. Two of the high use vegetation types, sweetgum and oak/pine, contained the highest tick densities. A non-parametric ANOVA and Dunns multiple comparison procedure was used to compare vegetation variables and mean numbers of flagged ticks by life stage, month and vegetation type. Mean numbers of ticks by life stage were compared between years using a Wilcoxon-Rank Sum test. Two species, the lone star tick and the deer tick (*Ixodes scapularis*, previously known as the blacklegged tick, *Ixodes dammini* [Oliver and others 1993]), were tested for Lyme Disease and two strains of Ehrlichiosis, human monocytic ehrlichiosis (HME) and human granulocytic ehrlichiosis (HGE), using Polymerase Chain Reaction methods. Neither

Lyme disease nor HGE were detected in any of the sampled ticks. However, HME occurred in four ticks in 1999 in the sweetgum and tallgrass vegetation types. It was found again in 2000 in four ticks in the unburned oak/sweetgum and oak/pine vegetation types. Observed differences in tick abundance and seasonality by vegetation type and the occurrence of tick-borne disease is being used by the Park to aid in determining future management objectives and directing future monitoring and research efforts.

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INTRODUCTION

Two families of ticks, *Ixodidae* (hard ticks) and *Argasidae* (soft ticks), are present in North America. Both families can transmit disease, but hard ticks are more important as vectors of human disease (NPSa 1994). Worldwide, ticks are one of the primary vectors of human disease, second only to mosquitoes. Ticks are also the leading arthropod vectors in disease transmission to people in the United States (AFPM 1998). Additionally, tick-borne disease transmission is on the rise within the United States (AFPM 1998). Ticks have a wide range of hosts, are extremely hardy, and have high reproductive potential (NPSa 1994, AFPM 1998). They may also feed on many different hosts during their life cycle, which can last several years. Thus, pathogen attainment and dissemination is highly probable (AFPM 1998).

Ticks can transmit numerous human diseases. They include Rocky Mountain Spotted Fever, Colorado Tick Fever, Tick-borne Relapsing Fever, Tularemia or rabbit fever, Tick Paralysis, and Babesiosis (NPSa 1994, AFPM 1998). Three tick species that occur in Arkansas are capable of transmitting Lyme and/or Ehrlichiosis to humans: the deer tick (*Ixodes dammini*, previously known as the blacklegged tick, *Ixodes scapularis* [Oliver and others 1993]), American dog tick (*Dermacentor variabilis*), and lone Star tick (*Amblyomma americanum*). All three of these arthropods can carry the spirochete *Borrelia burgdorferi*, which causes Lyme disease (Taylor 1991, Schulze and others 1984, Anderson and others 1987, Magnarelli and Anderson 1988, Feir and Reppel 1990). Bacteria which cause Ehrlichiosis (*Ehrlichia spp.*) (Walker 1996) can infect lone star and deer ticks. The American dog tick is one of the more important species occurring in

Arkansas, but not because of its abundance. Rather, the tick is an especially important vector of spotted fever (Lancaster 1973).

Lyme disease was first recognized in 1975 (Steere and Malawista 1977) and has since become the most commonly reported vector-borne disease in the United States (Miller and others 1990, NPSa 1994). Lyme disease is transmitted primarily through tick bites. Small mammals, particularly the white-footed mouse (*Peromyscus leucopus*) are natural reservoir hosts of *B. burgdorferi* (Mukolwe and others 1992). Early stages of Lyme disease, which occur a few days to a few weeks after the bite of an infected tick, are characterized by an expanding circular rash around the site of the tick bite, and flu-like symptoms such as headache, muscle aches, stiff neck, fever, and sore throat. These symptoms vary considerably from patient to patient (NPSa 1994). The rash can be circular with a clear center, red throughout, blotchy in appearance, or absent altogether. Similarly, the flu-like symptoms are quite variable, and sometimes do not appear.

Early symptoms generally disappear, even without treatment. However, later stages can be quite severe and are difficult to treat (NPSa 1994). The symptoms of advanced Lyme disease also vary considerably from patient to patient. Some patients experience episodic bouts of severe arthritis within their large joints (knees, hips, etc.). Others experience no arthritic symptoms, but do suffer from a variety of neurological symptoms, including tingling or numbness in the extremities, Bell's Palsy, extreme fatigue, severe headaches, stiff neck, difficulty concentrating, and memory problems. Other patients have both arthritic and neurological symptoms and /or a variety of less common problems with other body systems. The vagueness and variability of these symptoms have resulted in frequent misdiagnoses of the disease (NPSa 1994). Left

untreated, Lyme disease can progress to more serious ailments involving joint, nerve, or heart tissue damage (NPSa 1994). Occurrence of Lyme disease increased approximately 93% from 1980 to 1990 (AFPM 1998). Consequently, it is the most common tick-borne disease reported in the United States. Between 1988 and 1997, 188 cases of Lyme disease were reported in Arkansas (personal communication with Karl Long, Arkansas Department of Health).

Ehrlichiosis is caused by several species of pleomorphic coccobacilli, and are in the family Rickettsiaceae, tribe Ehrlichiae, genus *Ehrlichia* (AFPM 1998). It has been suggested that *Ehrlichia spp.* evolved in close association with ticks (Walker 1996). Human monocytic ehrlichiosis (HME) is caused by *Ehrlichia chaffeensis* and was first isolated in 1990 from a soldier at Fort Chaffee, Arkansas (AFPM 1998). Human granulocytic ehrlichiosis (HGE), another type of human ehrlichiosis, is caused by an *Ehrlichia equi*-like organism (Walker 1996). It was first reported in 1994 (AFPM 1998). Ehrlichiosis, like Lyme disease, is symptomatic in that symptoms can go unnoticed or they can become severe enough to cause death. Symptoms usually first appear after an incubation period of up to 21 days. Common symptoms generally include high fever, headache, malaise, myalgia, nausea, vomiting and anorexia. Severe symptoms include acute renal failure, encephalopathy, and respiratory failure (NPSa 1994, AFPM 1998). *Ehrlichia chaffeensis* has been found in two different tick species, the American dog tick and lone star tick. Human ehrlichiosis occurs in geographic regions similar to those of the lone star tick. As such, the lone star tick has been identified as the source of HME (AFPM 1998). White-tailed deer (*Odocoileus virginianus*) are a natural host for HME and have been indicated as the source of infection for all lone star tick life stages.

However, deer ticks have also been implicated as candidate vectors of HGE (AFPM 1998). Fifty-five cases of Ehrlichiosis were documented from 1994 to 1997 in Arkansas. In 1998 four deaths occurred in Arkansas due to this disease (personal communication with Karl Long, Arkansas Department of Health).

Tick abundance and tick-borne diseases, specifically Lyme disease and Ehrlichiosis, are concerns at Arkansas Post National Memorial (ARPO). Six visitor complaints in 1997 and a drop in visitation by approximately 18% (Lind 1998) during the summer of 1998 can partially be attributed to a perceived increase in tick abundance. To date, there has been one confirmed case of Lyme disease and three confirmed cases of Ehrlichiosis in dogs (*Canis familiaris*) at ARPO (Wood 2000). The latter resulted in the deaths of all three dogs. Additional anecdotal evidence of the occurrence of tick-borne diseases includes testing completed by a local physician, Dr. Stan Burleson, in 1996. Dr. Burleson tested 15 ticks, of unknown species or life stage, for Lyme disease using immunofluorescent analysis (IFA). In a 1999 phone conversation, Dr. Burleson stated that 40% (6 of 15) were positive for carrying *B. burgdorferi.*

National Park Service (NPS) management policies allow control of disease vectors when "necessary for visitor safety and health" (NPSa 1994). Decisions to initiate control are to be based on local research, and must comply with established planning procedures, including provisions for public review and comment (NPSa 1994).

Vegetation manipulation using prescribed fire or mowing is generally more desirable than chemical control measures to reduce the number of ticks within the NPS system (NPSb 1994). Quellette and others (1997) found that host utilization of specific vegetative habitat types is perhaps the most important single factor in determining tick

abundance. Thus, before any tick control measures are undertaken, information must be gathered on the relative abundance of ticks per vegetation type and the frequency of tick-borne diseases by ticks and host species at ARPO.

OBJECTIVES

The objectives of this study were to determine the:

(1) relative abundance of ticks by species and vegetation class, and

(2) frequency of *Borrelia burgdorferi* and *Ehrlichiae spp*. by tick species and vegetation class at ARPO.

LITERATURE REVIEW

Tick Life History

Ticks belong to the order Acarina and consist of two families, Ixodidae (hard ticks) and Argasidae (soft ticks). Hard ticks are known to exclusively feed once between each host-seeking stage. *Ixodes spp.* generally feed on three distinct hosts. The hosts can be the same throughout all life stages or consist of different species. Ticks that follow this behavior are described as three-host ticks.

Ticks of the genera *Ixodes, Amblyomma,* and *Dermacenter* have four basic life stages (Mount and Haile 1989, Lord 1992, Fish 1993) consisting of eggs, larvae, nymphs and adults. A blood meal must be obtained in each successive life stage, with the exception of eggs, in order to progress to the next stage of development. Eggs produced by Ixodid ticks are laid en masse within a protected area. A single cluster of eggs can number in the thousands (AFPM 1998). Adult Ixodid ticks mate primarily on their host (AFPM 1998) and generally lay eggs in May. Larvae hatch in about a month and start questing. Questing is a behavior in which a tick actively seeks a host by climbing vegetation, or other structures, and positioning itself so that its first pair of legs are available to grasp the host as it moves by. Host selection is species specific, and is dependent upon tick life stage and height from the ground at which questing takes place (AFPM 1998).

Usually 3-5 days after a successful blood meal, larvae drop to the ground and molt into nymphs. Molting can take up to 35 days. Nymphs then seek another host for a blood meal. Four to five days after the blood meal, nymphs drop to the ground where they reside in available microhabitats for approximately 42 days before molting into

adults (Fish 1993). The timing of tick drop-off is correlated with the host's behavior pattern and is influenced by photoperiod, which tends to disperse them in optimal habitats for development and reproduction (Sonenshine 1993). Ticks reside in the microenvironment while molting or sheltering between periods of host-seeking activity (Sonenshine 1993). This environment is made up of the soil and soil-vegetation interface and includes leaf litter (Sonenshine 1993). Feeding behavior is different between adult males and females (AFPM 1998). Adult females feed to engorgement in approximately 7 days, while adult males feed erratically on the final host (Fish 1993, AFPM 1998). Both sexes die after reproduction (AFPM 1998).

Development in each life stage is delayed by specific functions such as blood meal digestion, molting, hatching, rest periods, and host seeking events (Fish 1993). Additional delays in development are caused from diapause events involving arrested development and behavioral changes (Fish 1993). Thus, a complete life cycle can range from 1 to 6 years (Fish 1993). Generally this process takes two years (AFPM 1998).

Seasonal Occurrence

LONE STAR TICK

In New Jersey, Schulze and others (1986) concluded that all stages of the lone star tick coincided with those of the deer tick, but were not as abundant. Conversely, Lancaster (1973) states that the lone star tick is the most common species in Arkansas, with its abundance peaking in August in northwest Arkansas. Adult lone star tick population peaks have also been found to occur in late May and early June (Semtner and Hair 1973). Nymphs are documented as usually occurring in peak numbers in May

(Schulze and others 1984, Lavender and Oliver 1996). Larvae peak from August to September (Semtner and Hair 1973, Schulze and others 1984) (Table 1).

DEER TICK

Several studies from different regions of the United States indicate that deer tick nymphs are most active during May-June (Main and others 1982, Schulze and others 1984, Ginsberg 1992, Mannelli and others 1994), larvae are most active from July-August (Main and others 1982, Schulze and others 1984, Wilson and Spielman 1985, Ginsberg 1992, Mannelli and others 1994) and adults are most active from April-May, and/or October-November (Schulze and others 1984, Benach and others 1987, Wilson and others 1990, Ginsberg 1992) (Table 1).

AMERICAN DOG TICK

Quellette and others (1997) state that in North Carolina numbers of adult American dog ticks peak in July and peak numbers of larvae occurred in October. Conversely, adults were found in February, April, and May, in Arkansas (Lancaster 1973). In the same study, larvae were found every month of the year and nymphs were most abundant from April - September (Table 1).

Tick Abundance and Density

METHODOLOGIES

Carbon Dioxide Traps. Carbon dioxide trapping is one method of capturing ticks and estimating tick abundance and density (Sonenshine 1993). Several variations of this method exist. Nonetheless, each one utilizes the same fundamental principle. Ticks are attracted via carbon dioxide, which is emitted by dry ice placed on cloth for a specified amount of time. Results are often reported as number of ticks collected per trap per unit

Table 1. Expected seasonal occurrence of ticks[1] in Arkansas County, Arkansas.

		Month											
Species	Lifestage	January	February	March	April	May	June	July	August	September	October	November	December
Amblyomma americanum	Adult				X	X	X		X		X	X	
	Nymph					X	X						
	Larvae						X	X	X	X			
Dermacentor variabilis	Adult		X		X	X		X					
	Nymph				X	X	X	X	X	X			
	Larvae	X	X	X	X	X	X	X	X	X	X	X	X
Ixodes scapularis	Adult				X	X					X	X	
	Nymph					X	X						
	Larvae						X	X	X				

[1] Lancaster 1973, Semtner and Hair 1973, Schulze and others 1984, Lavender and Oliver 1996, Main and others 1982, Ginsberg 1992, Mannelli and others 1994, Wilson and Spielman 1985, Benach and others 1987, Wilson and others 1990, Quellette and others 1997.

time. However, because the area sampled is dependent on tick species, difficulty arises when trying to expand data collected by this method to a common unit for comparison purposes. Lone star ticks are more aggressive than deer ticks when searching for a blood meal. As such, they can be attracted from several meters away by carbon dioxide traps (Sonenshine 1993). Sampling area also depends upon the size of the cloth used for sampling, the amount of dry ice used, and the length of time each area is sampled. Koch (1987) found that by using a 0.7-m X 0.9-m cotton cloth panel with a 113 - 227g cube of dry ice placed at its center, a 48m^2 area was effectively sampled over a period of one hour. Studies must utilize similar methodologies in order to compare results (Koch 1987, Ginsberg and Ewing 1989, Bloemer and others 1986, Grothaus and others 1976, Semtner and Hair 1973).

Flagging/Dragging. Flagging is another method commonly used to collect ticks for abundance and density estimation. This method utilizes cloth attached to either a drag or flag whereby vegetation is sampled either behind or before the researcher, respectively. The movement of cloth that is attached to each of the apparatuses attracts ticks. Transects are usually delineated and then sampled for a predetermined amount of time. This method is more time intensive than that of carbon dioxide trapping but is not as species specific. Thus, tick species are more evenly sampled. Results are often reported as number of ticks collected per minutes walked. However, ticks obtained from flagging or dragging sessions can also be expanded to a number per unit area. Transect length and flag or drag widths are used to compute the area sampled.

ESTIMATES OF TICK ABUNDANCE AND DENSITY

Tick abundance is affected by several biotic and abiotic factors, singularly or in combination. These factors include host species and abundance, climatic conditions, habitat, and photoperiodic regimes. Many studies offer only rudimentary estimates of tick abundance such as high, moderate, and low (Sonenshine 1993). Several studies have reported gross abundance and density estimates. Those reported for dry ice estimates ranged from 6.5 to 54.3 ticks per hour sampled (Bloemer and others 1986, Koch 1987). Thus, when using Koch's (1987) estimate of area sampled by dry ice, an approximate range of dry ice estimates equate to 0.13 to 1.12 ticks/m^2. Area-based flagged estimates ranged from 0.1 to 321.0 ticks per 1m x 1000m transect, or per 1000m^2 (Cully 1999) in one study and 0.3 to 415.0 per 21.9m^2 in another (Semtner and Hair 1973, Semtner and others 1971a). Thus, area-based flagged estimates of tick density ranged from <0.01 to 18.95 ticks/m^2.

Vegetation Relationships

Habitat type and or specific vegetative components have been linked with tick habitat suitability (Sonenshine and Levy 1972, Semtner and Hair 1973, Ginsberg 1992, Mannelli and others 1994, Schulze and others 1986). Typical tick habitats include brushy forest environments and their associated ecotones (Goddard 1997). Literature suggests that open areas such as grass or prairie habitats with little shade support fewer numbers of ticks (Schulze and others 1986).

LONE STAR TICK

Lancaster (1973) indicates that lone star ticks cannot survive exposure to the sun. For this reason, they are found in shaded areas. Semtner and others (1971a) found that

high populations of adult lone star ticks were found in habitats where less than 25% of the ground was covered with leaf litter. Nymphs were more abundant in areas with greater than 25% leaf litter coverage. As such, leaf litter was suggested to be more desirable as overwintering habitat for larvae and nymphs. Davidson and others (1994) found that larva numbers were reduced when an area was burned. Reductions were associated with reduced litter depth, which consequently lowered habitat suitability.

Typical lone star tick habitat includes upland oak/hickory (*Quercus/Carya sp*.), bottomland oak/hickory, upland pine (*Pinus spp*.) and meadows (Koch 1984). Lone star tick nymphs were found to be abundant in forested (Ginsberg 1992, Davidson and others 1994) and grassy habitats (Semtner and Hair 1973). Semtner and others (1971a) found that lone star tick adults were more prevalent in brush where coverage of the ground by undergrowth vegetation was greater than 75%. Nymphs were found to occur in higher numbers in areas where brushy vegetation was 25% or less. Vegetation in grassy habitats 1.2m and shorter were also important in producing tick numbers within limited distances to associated ecotones ($\leq$ 46m). Lone Star ticks have also been found in pine, hickory, maple (*Acer spp.)*, oak, sassafras (*Sassafras albidum*), persimmon (*Diospiros virginiana*) and winged elm (*Ulnus alata*) habitats (Semtner and Hair 1973). Ticks have also been found in openings in forest canopy and Johnsongrass (*Sorghum halepense*). In an earlier study, Semtner and others (1971a) found higher populations of lone star nymphs where understory density was light, whereas slightly higher adult populations were concentrated in thicker understory vegetation. It was also determined that adult lone star ticks migrated down vegetation to the soil and/or duff as temperatures rose (Semtner and others 1971b).

DEER TICK

Deer tick habitat consists of leaf litter and low vegetation (NPS 1994a). Alternatively, adult deer ticks have been found to be more prevalent in shrub habitats greater than one meter in height. However, they have also been found in beach grass (*Ammophila sp.*) and shrub habitats less than a meter in height (Ginsberg 1992). Wilson and others (1990) found no difference between forest habitat and brush/shrub habitats in the abundance of either larvae or nymphal deer ticks. Conversely, Ginsberg (1992) states that nymphs and larvae are more common in leaf litter in wooded habitats than in open grass-shrub habitats. Schulze and others (1986) suggested that habitat types are only gross mechanisms for projecting tick populations in a particular area. Factors suggested to support populations of deer ticks include climate, host abundance and movement patterns, composition and structure of the dominant vegetation, and successional trends in plant communities and microclimates (Schulze and others 1986). The presence of ticks within an environment is said to be a function of host activity (Goddard 1997).

AMERICAN DOG TICK

Sonenshine and Levy (1972) found that the American dog tick primarily occurred in forest/field ecotones. However, they were also found in forb and low-deciduous forest habitats. Ticks were found to prefer mixed upland and hickory associations (Sonenshine and Levy 1972). Few differences in tick distribution were found in relation to forest vegetation classified by various height categories. Similarly, Ginsberg (1992) found that American dog ticks were common in grass, shrub and forest habitats.

Sonenshine and Levy (1972) found larva American dog ticks primarily in ecotones. Adults were more abundant in mesic (mixed-upland and hickory-dominant)

types. Zimmerman and others (1987) found that a majority of larvae and nymphs were found on white-footed mice in wooded habitats. However, few occurred on mice in old field habitats. Ginsberg (1992) states that adult dog ticks have a tendency to quest for hosts along trails and that they are more common on trails, than off. Additionally, the American dog tick has a tendency to be more abundant at the sides of roads or trails than in uninterrupted vegetation.

Tick Population Reduction

Several strategies to manage tick abundance are currently in use. They include habitat modification, biological control, elimination or depravation of hosts, integrated pest management (IPM), and treatment of vegetation with acaricides. Most reduction measures focus on reducing either tick abundance or the frequency of tick-borne diseases to acceptable levels. Tick reduction is cost intensive. As such, there have been studies to evaluate the economic thresholds for specific tick species in selected areas. Thresholds are generally dependent upon human visitation and tick abundance (Sonenshine 1993). Mount and Dunn (1983), in a study conducted at Wister Lake State Park in LeFlore County Oklahoma, determined that the economic threshold for the lone star tick was 0.65 ticks per one hour of carbon dioxide sampling.

Innate predators have been documented to reduce tick abundance (Sonenshine 1993) and include the helmeted guineafowl (*Numida meleagris*)(Duffy 1992); cattle egrets (*Bubulcus ibis*); chickens and other pecking birds; shrews (*Sorex spp.*) and other small mammals; fire ants (*Solenopsis spp.*); spiders; and beetles. Parasites like Chalcid wasps (*Hunterellus hookeri*) can naturally reduce tick abundance (Sonenshine 1993). Samish and Glazer (1990) found that 100% of ticks placed in petri dishes with

entomopathogenic nematodes (*Steinernema carpocapsae*) died after four days of exposure. Consequently, it was suggested that entomopathogenic nematodes might potentially be used for biological control of tick abundance. Nematodes and engorged female ticks prefer the same habitat (Samish and Glazer 1990).

The primary technique currently used to reduce tick abundance involves some form of acaracide application, usually applied to vegetation or hosts. Several different acaracides exist including coumaphos, diazinon, chlorpyrifos, carbaryl, propoxur, cythion, and ivermectin (Sonenshine 1993).

Favorable results have been achieved through habitat modification, which includes controlled burning, mowing, and removal of leaf litter and forest canopy. Unfortunately, some of these methods have not always had the desired effect. In some circumstances, ticks were provided with renewed vegetative growth and increased host abundance shortly after the technique was applied. Consequently, tick abundance increased shortly thereafter (Sonenshine 1993). Clear goals (e.g., reduce tick abundance or reduce tick-borne disease frequency) need to be established with appropriate methodologies. Otherwise, a reduction in tick numbers may be achieved but not the goal of tick-borne disease reduction. For example, Mather and others (1993) found that abundance of deer tick nymphs decreased by 49% after burning a portion of their study area. However, the prevalence of nymphs infected with Lyme disease remained the same.

A study involving fire regimes in prairie habitats found that 75% of Gulf Coast ticks (*Amblyomma maculatum*) were killed when fire temperatures were greater than 330°C (Scifres and others 1988). Davidson and others (1994) reported similar findings with lone star tick abundance in a study on the effects of annual and biennial burning. As

such, it was suggested that typical prescribed fire regimes for the achievement of wildlife management objectives could be an effective method for reducing lone star tick abundance. Tick numbers were reduced by 80%, 75% and 70%, for larvae, nymphs and adults, respectively, in annual burns. Biennial burning did not reduce numbers as effectively but did result in a 48%, 73%, and 65% reduction for each respective life stage.

Mount (1981b) found that significant lone star tick reductions could be achieved when combinations of vegetative manipulation techniques were used. Techniques included partial removal of the overstory, complete removal of the understory, and the establishment of a frequent mowing regime. Adult females were reduced by 78% and males by 76%. Nymphs were reduced by 93% and larval by 84%.

In an editorial on natural population regulation and management of the black-legged tick, Ginsberg (1993) states that management of deer populations may decrease the density of ticks. However deer must be a limiting factor for that tick population. He also mentioned, with regard to the effectiveness of pesticides placed within a host's habitat or in its food supply, that success depends upon the population regulatory systems of the targeted tick species. In a study to evaluate host-targeted permethrin application in the reduction of black-legged ticks, Stafford (1992) found no significant differences between the control and studied populations or in frequencies of ticks with Lyme disease. Daniels and others (1991) reported similar results. Conversely, treatment of white-tailed deer with ivermectin treated bait significantly reduced numbers of lone star ticks (Pound and others 1996). Permethrin based acaricide was also successfully used in a study by Deblinger and Rimmer (1991) to reduce black-legged tick abundance. This was accomplished by placing cotton impregnated with permethrin in small mammal habitat,

which reduced the number of ticks on mice. Consequently, visitors acquired fewer ticks at the study site. Similar results were obtained by Sonenshine and Haines (1985) when pesticide was used as an oil or dust and applied to the coats of small mammals. An 81% reduction of immature American dog ticks resulted in one study area, while a reduction of 98% occurred in another. Schulze and others (1991) evaluated the short-term effectiveness of granular acaricide applications on deer tick nymphs and larvae. Nymphs and larvae were significantly reduced on hosts as well as in the habitat. A host exclusion study, where white-tailed deer were excluded from an area, resulted in reductions of lone star tick life stages (Bloemer and others 1986). Larvae were reduced by 98%, nymphs by 38% and adults by 22% (Bloemer and others 1986). Repeated sampling of tick populations without replacement can reduce tick density (Kramer and others 1993). However, tick abundance and the frequency and thoroughness of sampling determines if tick reductions will occur (Kramer and others 1993). A 50% reduction of adult *Ixodes pacificus* (Western black-legged tick) populations resulted in a study by Kramer and others (1993). However, Lane and others (1985) did not alter tick abundance when they sampled without replacement.

Regardless of the reduction method utilized, control measures should tailor themselves to specific factors, such as tick biology and seasonal occurrence, environmental and human safety concerns, type of habitat involved, human population characteristics (density and activity), incidence of tick-borne disease, a predetermination of thresholds, and an idea of feasibility (AFPM 1998).

Lone star ticks have been observed to form clusters (a group set close together) that are related to soil moisture and overhead shade (Goddard 1997). This predictable

behavior may aid in population management efforts. Few ticks were found in areas with full sunlight. The majority (70%) was found in areas with shade. Goddard (1997) suggested that shaded areas could be flagged in the spring to delineate where ticks occurred. Pesticides could then be used in the areas where clusters were identified. Mount (1981a) found that when acaricides were applied via an air-blast sprayer in selected camping and picnicking areas, 50% to 80% reductions of lone star nymphs and adults resulted. However, it was dependent upon chemical formulation and application rate.

STUDY AREA

This study was conducted at ARPO, located in Arkansas County, Arkansas, United States (Figure 1). ARPO is a peninsula surrounded by water, and totals 157.5 hectares**.** The land-based portion, 117 hectares, is characterized by terrace landscapes, flat terrain, and various stands of upland and lowland hardwoods. Bayous and swamps are interspersed throughout the area. Manicured lawns, prairie, and tall-grass areas also exist within the Park. As such, an abundance of flora and fauna resides both on land and in water. Moore Bayou and Post Bayou lie along the north/northwest border and Post Lake, a backwater of the Arkansas River, lies on the north and northeastern border. Both bayous, as well as the backwater, empty into the Arkansas River, which borders the southern edge of the Park.

Over 300 years of European occupation has occurred at the Park. Consequently, the land-based portion presents a mosaic of different successional stands. Thus, 12 general vegetation types have been delineated at the Park (Table 2, Figure 2). Of these 12 types, the superintendent has designated five, excluding mowed areas, as high visitor use areas. They are the oak/pine, oak/hickory, oak/mixed, sweetgum, and tallgrass types (Table 2).

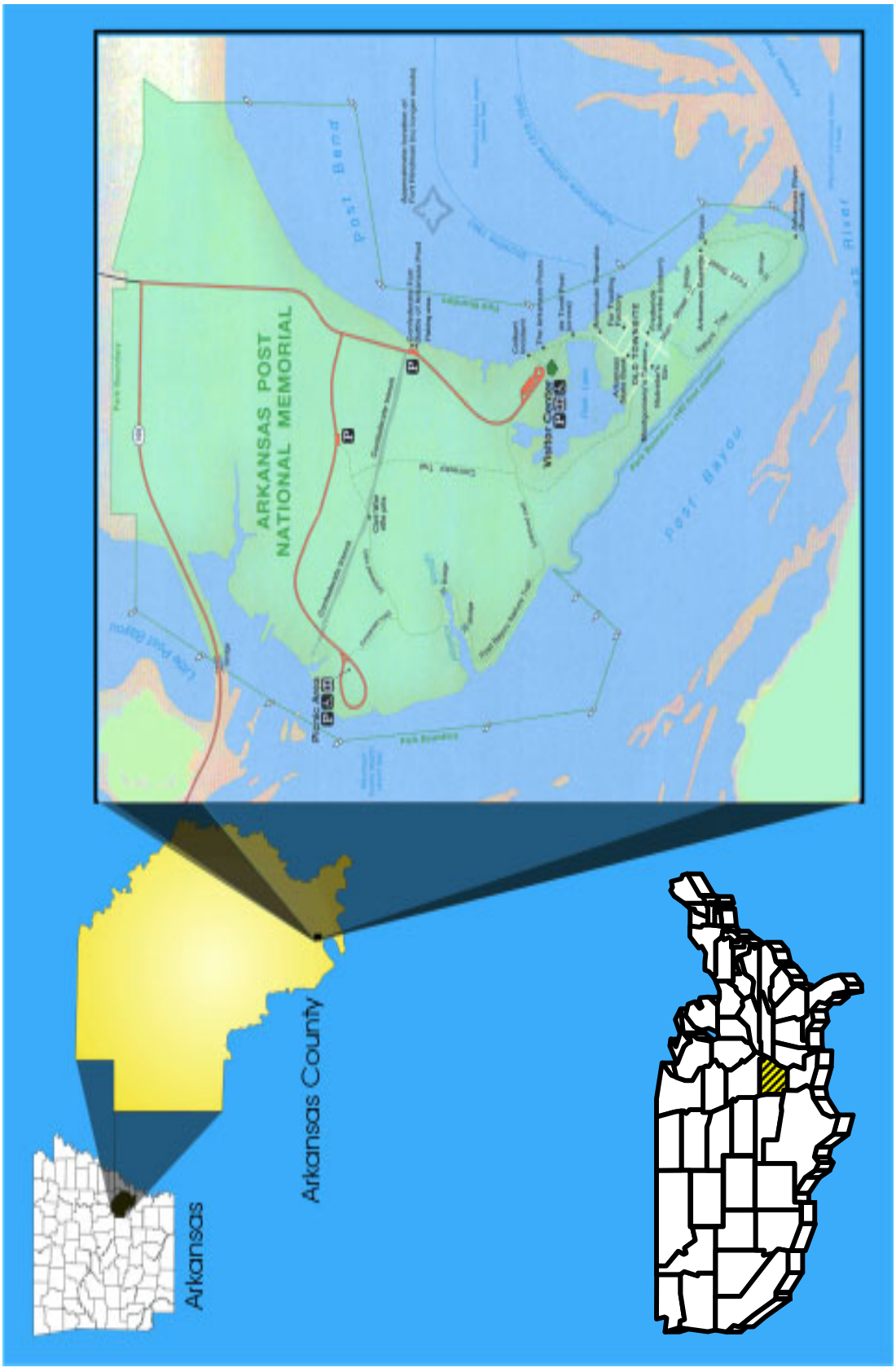

Figure 1. Site location of the tick abundance and disease studies, Arkansas Post National Memorial, Arkansas County, Arkansas, United States.

Table 2. Description of general vegetation types at Arkansas Post National Memorial, Arkansas County, Arkansas.

Vegetation type	$\bar{x}$ BA m^2/ha (SD)	Dominate species	Scientific Name	% Dominant species
Oak/Hickory[1]	30.2[2]	Water Oak	*Quercus nigra*	26
	(4.13)	Cherrybark Oak	*Quercus pagoda*	25
		Pecan Hickory	*Carya illinoenis*	9
		Eastern Red Cedar	*Juniperus virginiana*	13
		Other[3]		27
Oak/Pine[1]	22.96	Cherrybark Oak	*Quercus pagoda*	21
	(6.68)	Water Oak	*Quercus nigra*	28
		Sweetgum	*Liquidambar styraciflua*	17
		Eastern Red Cedar	*Juniperus virginiana*	7
		Post Oak	*Quercus stellata*	7
		Other		20
Oak/mixed spp.[1]	10.3	Pecan Hickory	*Carya illinoenis*	31
	(2.74)	Water Oak	*Quercus nigra*	27
		Cottonwood	*Populus deltoides*	14
		Other		28
Burned Oak/	13.0	Willow Oak	*Quercus phellos*	24
Sweetgum	(4.73)	Cherrybark Oak	*Quercus pagoda*	14
		Water Oak	*Quercus nigra*	19
		Southern Red Oak	*Quercus falcata*	17
		Other		26
Unburned Oak/	12.2	Water Oak	*Quercus nigra*	23
Sweetgum	(2.30)	Cherrybark Oak	*Quercus pagoda*	19
		Southern Red Oak	*Quercus falcata*	13
		Willow Oak	*Quercus phellos*	13
		Winged Elm	*Ulmus alata*	4
		Sweetgum	*Liquidambar styraciflua*	8
		Post Oak	*Quercus stellata*	6
		Eastern Red Cedar	*Juniperus virginiana*	4
		Other		10
Sweetgum[1]	36.7	Sweetgum	*Liquidambar styraciflua*	100
	(3.25)			
Sweetgum/	14.0	Sweetgum	*Liquidambar styraciflua*	83
Mixed	(4.93)	Other		17
Sweetgum/	16.6	Sweetgum	*Liquidambar styraciflua*	31
Oak	(5.72)	Cherrybark Oak	*Quercus pagoda*	17
		Winged Elm	*Ulmus alata*	11
		Water Oak	*Quercus nigra*	15
		Eastern Red Cedar	*Juniperus virginiana*	17
		Other		9

Table 2. Continued

Vegetation type	$\bar{x}$ BA m^2/ha (SD)	Dominate species	Scientific Name	% Dominant species
Cedar	22.0	Eastern Red Cedar	*Juniperus virginiana*	89
	(5.76)	Sweetgum	*Liquidambar styraciflua*	8
		Water Oak	*Quercus nigra*	2
		Other		1
Mowed w/o trees	0.0 (0.00)	Bermuda	*Cynodon dactylon*	100
Mowed w/trees	13.2	Post Oak	*Quercus stellata*	52
	(2.38)	Willow Oak	*Quercus phellos*	15
		Other		33
Tallgrass[1]	8.7	Sweetgum	*Liquidambar styraciflua*	89
	(3.02)	Pecan Hickory	*Carya illinoenis*	10
		Other		1

[1] Forested high visitor use vegetation types.
[2] Mean basal area m^2/ha.
[3] "Other" category may include Post Oak, Willow Oak, Cherrybark Oak, Water Oak, Green Ash (*Fraxinus pennsylvanica*), Osage Orange (*Maclura pomifera*), Box Elder (*Acer negundo*), Winged Elm (*Ulmus alata*), American Elm (*Ulmus americana*), Pecan Hickory, Sugar Berry (*Celtis laevigata*) and American Sycamore (*Platanus occidentalis*).

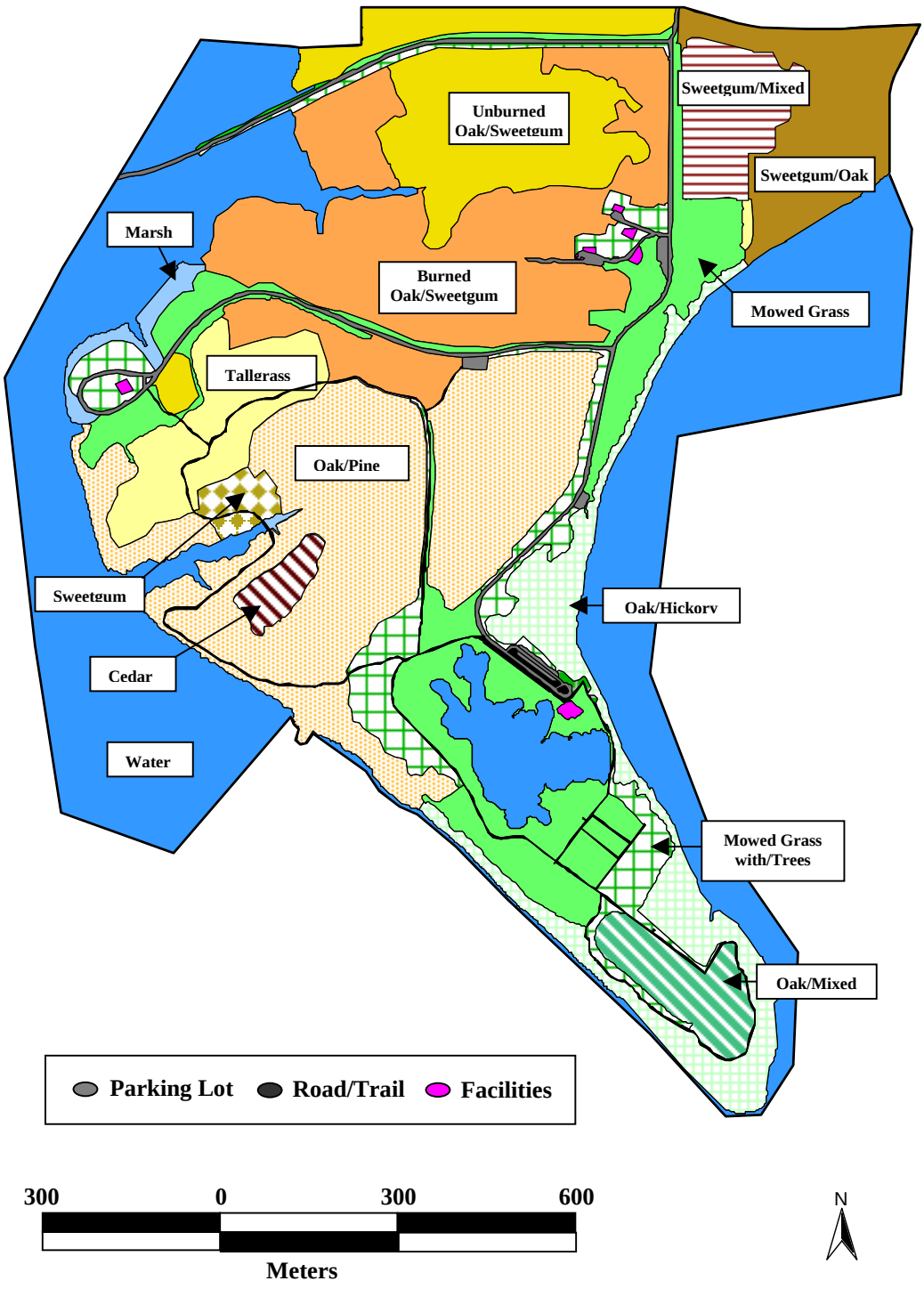

Figure 2. Vegetation types locations at Arkansas Post National Memorial, Arkansas County, Arkansas, United States.

METHODS

Plot Design

All tick and vegetation sampling was conducted in 2m x 6m plots (Figure 3). The number of plots per type was proportional to its respective area (Table 3). Additional plots were added to vegetation types with small areas so that adequate sample sizes could be achieved. Plots were placed a minimum of 50m from the edge of each vegetation type and spaced a minimum of 15m from each other. They were additionally arranged within each type based upon access.

Vegetation Sampling

Vegetation was sampled within each plot in June 1999. Plots were divided into three contiguous $2m^2$ subplots. Each $2m^2$ subplot contained one nested $1m^2$ quadrat (Figure 3) similar to that used by Thill and others (1993). A quadrat is the usual unit for biotic study and typically consists of $1m^2$ (Tulloch 1978). Litter depth was measured at three random points in each $1m^2$ quadrat and assigned to centimeter increment classes (0.00 - 1.99, 2.00 - 3.99, and 4.0 - 5.99). Percentage coverage of bare ground, leaf litter, forbs and grasses were measured via ocular estimation within each $1m^2$ nested quadrat and was based upon percentages (0-5, 6-25, 26-50, 51-75, 76-95, 96-100) as described by Daubenmire (1959). These percentages were used for consistency and comparison purposes as this method is one typically employed to sample vegetation (Elzinga and others 2000). Percentage canopy cover was estimated via densiometer once in each $2m^2$ subplot (Figure 3). Estimates of percentage of downed wood were similar to those of bare ground, leaf litter, forbs and grasses in that an ocular estimation by percentage was used. However, these estimates were taken once in each 2m x 6m plot. Vertical structure was

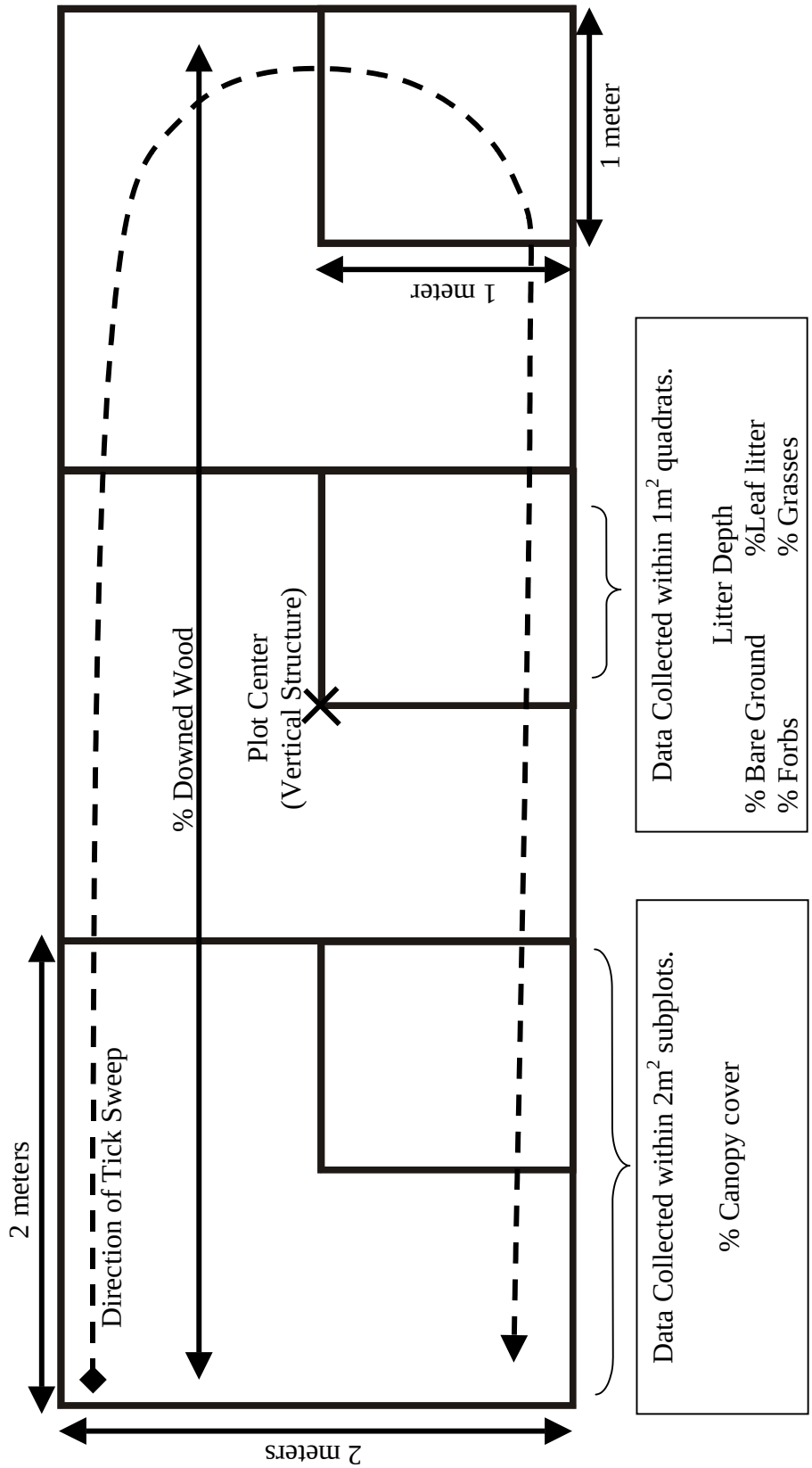

Figure 3. Data collection location within plots and plot design at Arkansas Post National Memorial, Arkansas County, Arkansas.

Table 3. Area, percentage of total area, and number of 2m x 6m plots by vegetation type at Arkansas Post National Memorial, Arkansas County, Arkansas.

Vegetation type	Area (ha)	% of total area	No. of plots
Oak/Hickory	9.2	8.0	8
Oak/Pine	26.1	22.8	22
Oak/mixed spp.	2.8	2.4	5
Burned Oak/Sweetgum	19.8	17.3	12
Unburned Oak/Sweetgum	13.8	12.0	16
Sweetgum	1.1	1.0	5
Sweetgum/Mixed	5.2	4.5	8
Sweetgum/Oak	5.9	5.1	5
Cedar	2.8	2.5	5
Mowed w/o trees	18.7	16.2	8
Mowed w/trees	3.5	3.1	9
Tallgrass	5.9	5.1	10
Total	114.8	100.0	113

sampled at plot center in each 2m x 6m plot using 0.5m x 0.5m density boards. Percentage of vertical structure in each of three height zones (0.00-0.49m, 0.50-0.99m, 1.00-1.50m) was measured (Figure 3).

Tick Sampling

A tick sweep (Figure 4) based on a design by Carroll and Schmidtmann (1992) was utilized to sample questing ticks. Due to its rigidity, this design was found to collect more ticks in dense brush and understory than traditional drag or flag designs.

Flagging sessions were conducted in 30-second intervals in each 2 x 6-m plot as suggested by Duffy and others (1994). Plots were sampled in their entirety in each vegetation type (Figure 3). Since the flagging apparatus had a one-meter square cloth attached, plots were sampled first on one side then the other (Figure 3). This facilitated the process but did not trample the vegetation. Each plot in each vegetation type was sampled once per month from May to October. All ticks were stored in a preservative solution that was developed by the United States Army Center for Health Promotion and Preventive Medicine – North, Ft. Meade, Maryland (USACHPPM-N). The preservative solution was mixed to specified proportions. One liter contained 400ml of deionized water, 400ml of dimethyl sulfoxide molecular (DMSO), 100ml of 5 molar sodium chloride (NaCL), 50 ml of tris-hydrochloride (pH 8.0), and 50ml of 0.5 molar ethylenediaminetetra-acetic acid disodium (EDTA). Total number ticks per plot were divided by 12, the area in a single plot, to correct to ticks/m^2.

Disease Assay

All collected ticks were identified to life stage and species using a 10 x 100 compound microscope and descriptive pictorial keys (PHS 1969, Sonenshine 1979,

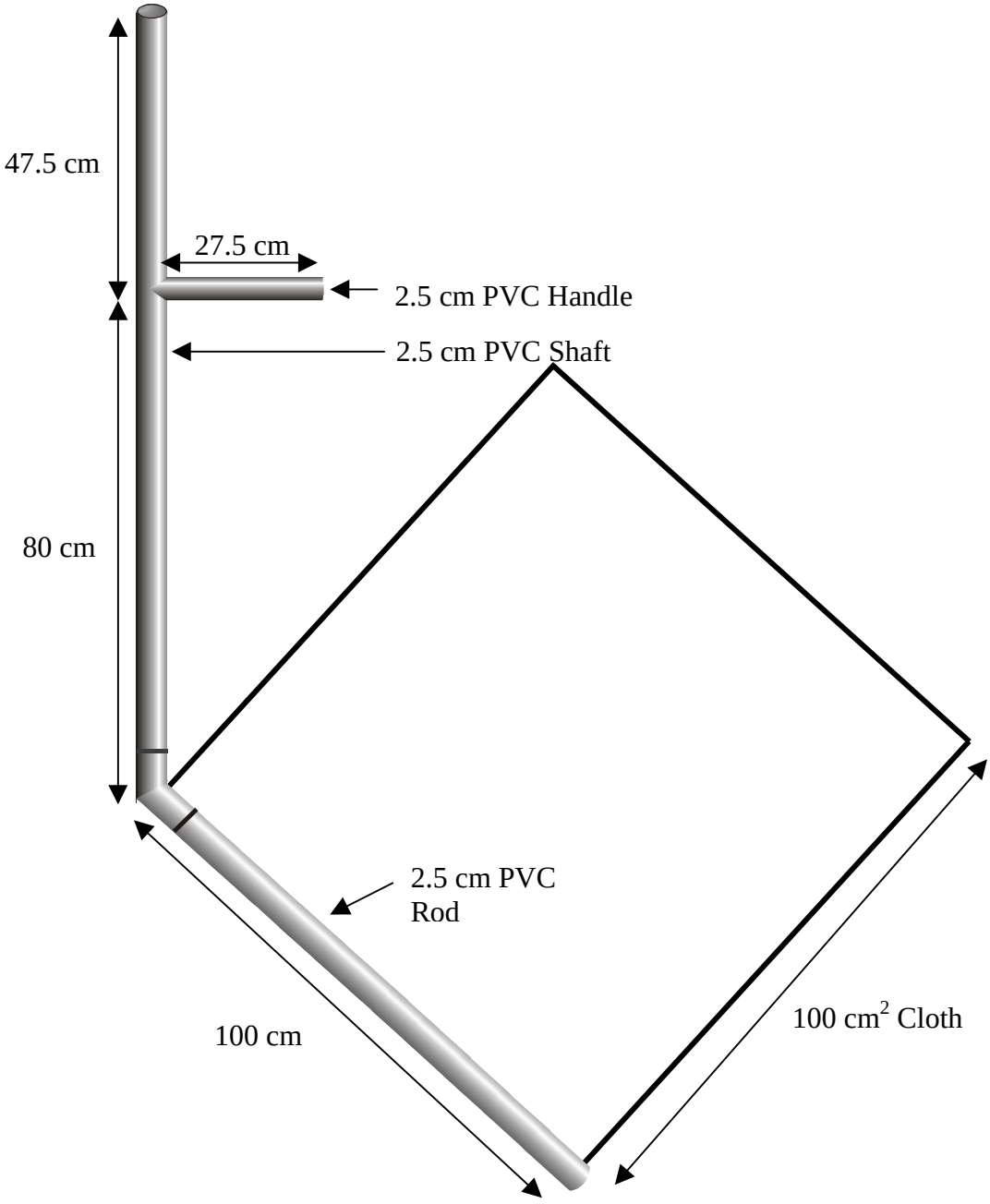

Figure 4. Tick sweep used to collect questing ticks at Arkansas Post National Memorial, Arkansas County, Arkansas.

Keirans and Litwak 1989, Lancaster 1973, NIH 1945). Consequently, they were labeled by month, vegetation type, and collection date.

Ticks were then randomly sampled without replacement and pooled by sex when applicable, life stage, vegetation type, and sampling period. All ticks were stored in the preservative solution for later analysis. Pooled samples consisted of 10 nymphs or 5 adults. However, nymphal numbers were reduced to 5 per sample if they were engorged. Pooled samples were then shipped to the USACHPPM-N laboratory for analyses.

Tick disease assay consisted of several in-depth processes. They included lysis and isolation of DNA for testing by Polymerase Chain Reaction (PCR) (SOP #3 2000), tick DNA detection of Genomic Tick DNA by PCR (SOP #5 1999), and detection of *Borrelia burgdorferi* as well as HME and HGE by PCR (SOP #4-LD 1999).

LYSIS AND ISOLATION OF DEOXYRIBONUCLEIC ACID (DNA)

Sterile 1.5 microliter (µl) centrifuge tubes were labeled according to the pooled sample to be tested. A control was established for each pooled sample and consisted of labeling a blank vial, identical to the others. The control served to determine if contamination in the lysis and isolation process occurred. Preservative solution was pipetted out of the pooled samples. Ticks were then taken out, washed with distilled water, and placed on a sterile pad to dry. One hundred microliters of lysis solution was then placed in the 1.5µl centrifuge tubes and set aside for later utilization.

Dried ticks were cut in half, lengthwise, using a sterilized surgical blade. Halved ticks were then divided equally into two separate 1.5µl tubes containing lysis solution. One tube was utilized for testing while the other was held in reserve should the pooled sample return positive. Sterilization procedures were followed between each process to

ensure that contamination did not occur. Generally, several vials were prepared and frozen at -70 degrees Celsius (°C). They were stored until a complete run (96 vials) was available for testing.

Once adequate numbers were prepared and ready for isolation, they were taken out of the freezer and thawed for 10 to 15 minutes. The isolation process involved preparing and labeling another set of 1.5µl microcentrifuge tubes, which corresponded with the previous set. Seven hundred microliters of guanadinium isothiocyanate and 400µl of buffer solution was added to the lysate solution in the initial set of centrifuge tubes. Guanadinium isothiocyanate inactivates any DNase or RNase in the solution so that tick DNA is not destroyed. Vials were then mixed in a vortex for approximately ten seconds or until the contents were well mixed.

Tubes were then placed in the centrifuge for five minutes at a speed equal to that of 14,000 times the normal gravitational force (g's). Afterwards, four hundred microliters of the clear aqueous upper layer was pipetted off and transferred to the pre-prepared isolation microcentrifuge tubes. Leftover organic material was discarded into appropriate hazardous waste containers. An equal amount of sodium acetate, 400µl, was then added to the aqueous phase solution along with an identical amount of 99% isopropanol. Sodium acetate precipitates DNA within the vials. Tubes were then centrifuged for 10 minutes at 14000 g's. Afterwards, the supernatant was discarded into an appropriate hazardous waste container.

A nucleic acid pellet, which contained the tick DNA, was left in the vial. One microliter of 70% ethanol was added to the pellet to clean it. Afterwards, the tube was inverted several times to mix the solution. The solution was again centrifuged at 14000

g's for five minutes. Liquid ethanol was then poured off of the vials and they were spun again in a heated vacuum centrifuge for 10 minutes at 14,000 g's. Fifty microliters of RNase free water was then added to the vials in order to reactivate the tick DNA pellet. Vials were then capped, placed in a heat plate at 65°C for 20 minutes and incubated.

Incubation was performed to ensure that the Tick DNA pellet reverted into a solution. At this point, samples were either frozen at -70°C or analyzed for genomic tick DNA (SOP #3 2000).

TICK DNA DETECTION OF GENOMIC TICK DNA BY PCR

This process was completed via PCR analysis. It consisted of labeling "Ready-To-Go®" PCR bead tubes so that they corresponded with sample DNA from the isolation procedure. This included a negative control tube that received master mix only; DNA template was not added to this tube. The master mix contained primers 16s+2 and 16s-1, which amplified the "a" segment of the 16s gene of tick RNA. This allowed for the detection of genomic tick DNA. The master mix, 24µl, was placed into the "Ready-To-Go®" PCR bead tubes and mixed via pipetting it in and out several times. DNA template, 1µl, was then added to each tube. Caps were immediately placed on the tubes at this point to prevent contamination. The tubes containing the master mix and template DNA, termed amplicons, were then placed into the thermalcycler.

A temperature regime was then conducted in a thermalcycler. The regime consisted of three cycles. In the first cycle, vials were heated up to 92°C and held for 60 seconds. The temperature was then reduced to 48°C for 60 seconds and raised to 72°C for 90 seconds. This cycle was repeated ten times. The second cycle consisted of heating the vials up to 92°C for 60 seconds then letting them cool to 54°C for 35 seconds.

Afterwards, the temperature was raised to 72°C for 90 seconds. This second cycle was repeated 32 times. The final cycle consisted of heating the vials to 72°C for seven minutes. They were then held at 4°C until the tubes were removed.

Electrophoresis (SOP #10 1999) was then conducted to determine if pooled samples were positive for tick DNA. A 1.5% agarose gel was prepared for a "Wide Range/Standard 3:1 Agarose" per 100ml buffer. One microliter of ethidium bromide (EtBr) was added to every 25ml of agarose gel. The EtBr binds to the tick DNA causing it to fluoresce under ultraviolet (UV) light. This allows bands of tick DNA, if present, to be viewed under UV light. After the gel was prepared, 1µl of loading buffer was added to each of the PCR tubes. Consequently, 5µl of "Ready-Load®" 100 base pair (bp) DNA Ladder solution was added to the first and last wells of the agarose gel. The ladder solution produces bands every 100bp, from 0bp to 1500bp, and serves as a point of reference when measuring DNA bands from samples. Approximately 5 to 10µl of sample amplicon was then added to the remaining wells. Electrophoresis was applied until the sample bands were within 0.5 inch from the next row of wells.

Analysis was determined by observing the DNA bands under an UV light. Presence of bands at about 300bp indicated that positive tick DNA was present in the sample. If all samples were negative then the reaction failed and the entire process was repeated. Contamination was determined not to have occurred if the negative control did not display a band at the 300bp level (SOP #5 1999).

DETECTION OF BORRELIA BURGDORFERI, *HME, AND HGE, BY PCR*

Tick-borne disease analysis, although requiring different primers, consisted of similar procedures. As such, only one description of the methodologies is given.

Initial amplification of the selected disease DNA used a pre-prepared "Master-Mix Rosa® primer" for each specific tick-borne disease. Consequently, 24µl of primer were added to each "Ready-To-Go®" PCR bead tube, including a control. Samples were mixed via pipetting the solution in and out. One microliter of DNA template was then added to each tube. Tubes were immediately capped to prevent contamination. Tubes were then placed in a thermalcycler that had been programmed for the following regime: 94°C for 45 seconds, 55°C for 45 seconds, and 72°C for 90 seconds. This regime was carried out 45 times. Afterwards, the samples were held at 4°C until further analysis could be completed.

The second amplification of the DNA began with the addition of 24.5µl of selected "Master Mix Rosa Primers®" into new "Ready-To-Go®" PCR bead tubes, including a control PCR bead tube. One-half of a microliter of Amplicon from the first amplification was added to the new set of PCR bead tubes. Again, they were immediately capped to prevent contamination. The samples were then placed in the thermalcycler at 94°C for 45 seconds, 55°C for 45 seconds, and 72°C for 90 seconds. This regime was repeated 45 times. Afterwards, they were placed on hold at 4°C until needed.

Disease presence/absence was then determined through electrophoresis, as described above (SOP #10 1999). If bands were present at the appropriate level, 236bp for *Borrelia burgdorferi*, then the sample was positive. If the negative controls presented bands at this level then they were contaminated. Consequently, analysis would have to be repeated. Ticks in pooled samples that tested positive were subsequently tested individually. The entire process described above was repeated (SOP 4-LD 1999) on individual ticks taken from positive pooled samples.

Lone star tick nymphs and adults were tested for Ehrlichiosis, HME and HGE, to determine the frequency of the bacterium per vegetation type by season and year. Since it has not been determined conclusively that the lone star tick can carry and transmit Lyme disease, only the presence/absence of *Borrelia burgdorferi* per pooled sample of each life stage was determined.

Deer tick nymphal life stages were tested for Lyme disease and HME to determine their frequency per vegetation type by season and year. Adults were not tested since most transmission occurs from the nymphal stage. In a 1998 phone conversation, Dr. Karl Neidhardt (Entomologist, United States Army Center for Health Promotion and Preventive Medicine-North. 4411 Llewellyn Drive. Ft. Meade, Maryland 20755-5225) stated that adults of this species are comparatively large and are generally removed by humans before they transmit the disease.

Due to monetary constraints, no other collected tick species were sampled for tick-borne diseases, but they were used to provide relative abundance of each life stage per vegetation type and season.

Data Analyses

An alpha of 0.05 was used on all data analyses and multiple comparison procedures (MCP). SAS (SAS Institute, Inc. 1999) was used on all statistical analysis. Due to the occurrence of non-normal data and the lack of constant variance, two key factors that are necessary for the successful completion of parametric tests and comparison of means, non-parametric tests were used to analyze all data.

All vegetation variables were averaged to produce a single data point per plot for analysis. Those variables estimated by percentages (bare ground, leaf litter, forbs,

grasses, and percent downed wood) were assigned numbers by category and then averaged so that means could be compared (e.g., 0-5% = 1, 6-25% = 2, 26-50% = 3, etc.). Vegetation type means were then rounded and reassigned to categories for placement in tables. Means were rounded up or down to the next whole integer, 0.5 was the cut off point. For example, a vegetation type with a mean of 1.53 was rounded to 2 and then assigned a category classification of 06-25% coverage. Vegetation variables were compared among vegetation types using Kruskal-Wallis non-parametric ANOVA and Dunn's MCP.

For each year, mean numbers of flagged ticks per plot were compared by life stage and sex (adults only) among vegetation types for each season using Kruskal-Wallis non-parametric ANOVA and Dunn's MCP to determine if differences existed among vegetation types by lifestage within each month. To determine if differences existed in lifestage totals among months and years, mean numbers of ticks for each life stage (all vegetation types combined) were compared by month using Kruskal-Wallis non-parametric ANOVA and Dunn's MCP, and between years using Wilcoxon-Rank Sum tests. Mean numbers of ticks per life stage and vegetation type were compared between seasons using Kruskal-Wallis non-parametric ANOVA and Dunn's MCP. A Wilcoxon-Rank Sum test was used to compare mean numbers between years by life stage (male and female adults were combined into one variable "Adults") and vegetation type to determine if differences existed by vegetation type between years.

RESULTS AND DISCUSSION

Vegetation

Within the forested vegetation types, mean litter depth was highest numerically in the sweetgum/oak vegetation type and lowest in the sweetgum type (Table 4). Of all vegetation types (excluding mowed areas [both mowed grass without and mowed grass with trees]), the unburned oak/sweetgum type had the lowest percentage coverage in all three vertical structure (Table 4). All vegetation types had similar percentage coverage of bare ground with the exception of the oak/pine and cedar types (Table 5). The oak/pine type was similar to all other vegetation types but was different from the cedar type in that it contained lower percentage coverage of bare ground. As such, the cedar type was similar to all other vegetation types with the exception of the oak/pine type. There were no differences in percentage of down wood among vegetation types. This may have resulted from the sampling strategy, the variance within each type, the multiple comparison procedure used, or from a combination of any or all of these. The tallgrass and mowed vegetation types contained similar leaf litter coverage and were the lowest ranking among all other vegetation types (Table 5). There was higher percentage coverage of forbs in the burned oak/sweetgum type than in either the oak/pine or oak/hickory types (Table 5). The mowed vegetation types contained more percentage coverage of grass than the oak/hickory, oak/pine, oak/mixed, and burned and unburned oak/sweetgum types. The tallgrass type contained less canopy cover than did any other type, excluding the mowed grass with/out trees type (Table 5).

Of the five high visitor use areas, mean litter depth was highest, numerically, in the oak/hickory type and lowest in the sweetgum type (Table 4). Percentage of vertical

Table 4. Mean litter depth (SE) and mean percentage coverage (SE) of vertical structure height by vegetation type at Arkansas Post National Memorial, Arkansas County, Arkansas.

Vegetation Type	Litter Depth (cm)	Vertical Structure % (0.0-0.5m)	Vertical Structure % (0.75-1.25m)	Vertical Structure % (2.0-2.5m)
Oak/Hickory[1]	2.97 ad[2] (0.17)	18 abde (6.19)	4 abc (1.83)	37 abc (14.97)
Oak/Pine[1]	2.32 a (0.21)	35 ab (7.80)	28 ab (7.98)	36 a (8.39)
Oak/Mixed spp.[1]	2.41 acf (0.18)	71 cd (13.82)	50 abc (15.81)	46 abc (21.41)
Burned Oak/Sweetgum	2.49 acf (0.17)	84 ac (8.50)	66 bd (11.42)	5 ab (3.34)
Unburned Oak/Sweetgum	3.09 ae (0.35)	8 bde (4.65)	2 ade (1.56)	7 ab (6.26)
Sweetgum[1]	0.70 bcg (0.08)	26 acde (13.27)	21 abc (8.86)	25 abd (12.94)
Sweetgum/Mixed	1.28 abgf (0.14)	46 acde (12.41)	48 bc (13.98)	88 cd (6.12)
Sweetgum/Oak	3.31 fde (0.30)	31 acde (18.33)	32 abc (19.34)	27 abc (18.81)
Cedar	0.82 bcde (0.13)	13 acde (6.04)	20 abcd (9.08)	60 adef (20.31)
Mowed w/o trees[1]	0.00 b (0.00)	0 e (0.00)	0 ce (0.00)	0 bf (0.00)
Mowed w/trees[1]	0.00 b (0.00)	0 e (0.00)	0 ce (0.00)	0 be (0.00)
Tallgrass[1]	1.10 bcf (0.26)	100 c (0.00)	45 abc (15.28)	40 abd (16.33)

[1] High visitor use areas.
[2] Letters that are the same within each column indicate no significant difference (p-value >0.05).

Table 5. Mean percentage coverage categories of habitat variables in vegetation types at Arkansas Post National Memorial, Arkansas County, Arkansas.

Vegetation Type	Bare Ground	Downed Wood	Leaf Litter	Forbs	Grass	% Canopy Cover (SE)
Oak/Hickory[1]	0-5 ab[2]	6-25	96-100 a	0-5 ad	06-25 ac	97 abc (0.84)
Oak/Pine[1]	0-5 a	6-25	76-95 a	6-25 a	0-5 a	97 a (0.37)
Oak/Mixed spp.[1]	0-5 ab	0-5	96-100 ab	26-50 bde	6-25 acd	97 abc (0.77)
Burned Oak/Sweetgum	0-5 ab	6-25	96-100 a	51-75 bc	0-5 ac	95 abc (1.60)
Unburned Oak/Sweetgum	0-5 ab	6-25	96-100 a	0-5 ad	0-5 ac	97 ab (0.74)
Sweetgum[1]	0-5 ab	6-25	76-95 ab	6-25 ace	6-25 bc	97 acd (0.66)
Sweetgum/Mixed	0-5 ab	0-5	96-100 a	6-25 ace	0-5 bc	99 bd (0.24)
Sweetgum/Oak	0-5 ab	6-25	96-100 a	6-25 ace	0-5 bc	99 bd (0.57)
Cedar	6-25 b	0-5	76-95 ac	0-5 ae	0-5 b	100 bd (0.26)
Mowed w/o trees[1]	0-5 ab	0-5	0-5 bc	0-5 ae	96-100 b	0 c (0.00)
Mowed w/trees[1]	6-25 ab	0-5	0-5 bc	0-5 ae	76-95 b	89 abcd (3.64)
Tallgrass[1]	0-5 ab	0-5	0-5 bc	6-25 ae	76-95 bd	16 c (7.29)

[1] High visitor use areas.
[2] Letters that are the same within each column indicate no significant difference (p-value >0.05).

structure (0.0m-0.5m and 0.75-1.25m) was higher in the oak/mixed type and lower in the oak/hickory type (Table 4). It was highest numerically in the oak/mixed and lowest in the sweetgum type in the 2.0m-2.5m category. Percentage coverage of bare ground was the same in all high visitor use areas. Percentage of downed wood was similar in the oak/pine, oak/hickory, and sweetgum types (Table 5). Percentage of leaf litter was similar in the oak/pine and sweetgum types. It was highest in the oak/hickory and oak/mixed types and lowest in the tallgrass type (Table 5) in the forested high use areas. The oak/pine, sweetgum and tallgrass types were similar in percentage of forbs in the high visitor use areas. The highest occurrence of forbs in these five types was in the oak/mixed type, the lowest occurred in the oak/hickory type (Table 5). Grass in these five types was lowest in the oak/pine type and highest in the tallgrass type. Canopy cover was similar in all but the tallgrass type in the high visitor use areas (Table 5).

These vegetation types are similar to tick habitats cited in literature in that they include brushy forest environments. These types of habitats are typical lone star tick habitats (Goddard 1997). Lone star tick habitat includes upland and lowland oak/hickory forests (Koch 1984). As such, lone star ticks are well adapted to forest communities (Sonenshine 1993). Lone star tick nymphs have been found to be abundant in forested (Ginsberg 1992, Davidson and others 1994) and grassy habitats (Semtner and Hair 1973). Lone star ticks have also been found in pine, hickory, oak, persimmon and winged elm habitats (Semtner and Hair 1973). Sonenshine (1993) states that lone star ticks are found predominantly in forested habitats, especially in second growth forests with dense understories. However, they are also found in mature stands (Sonenshine 1993).

Oak/hickory associations are one of the predominant habitat types in the south central United States that support lone star ticks (Sonenshine 1993).

Semtner and others (1971a) found that high populations of adult lone star ticks were found in habitats where less than 25% of the ground was covered with leaf litter. Nymphs were more abundant in areas with greater than 25% leaf litter coverage. Davidson and others (1994) found that larva numbers were reduced when an area was burned. Reductions were associated with reduced leaf litter. Consequently, areas with adequate amounts of leaf litter would be expected to contain large numbers of larva.

If vegetative manipulation is a strategy that can be used to reduce tick abundance, then mowing and burning should be considered. Thus, prescribed fire could be used in the tallgrass type. However, it should be avoided in the forested types because of the needed burn frequencies, which could kill existing trees, necessary to reduce ticks. Davidson and others (1994) found that annual or biennial burns reduce tick numbers by eliminating ticks and their required habitat. Sonenshine (1993) found that tick abundance increased as burning frequency decreased due to the increased growth of vegetation over time, which provides habitat for ticks and hosts. Fire periodicity in wooded areas of the Park typically consists of 5 to 10 year cycles. As such, tick abundance would be expected to increase. Hence, burning to reduce ticks should only occur in areas that are to remain or revert to grass types.

Also, tick reduction efforts should be limited to the high visitor use areas because visitors and employees do not normally access the other areas. Visitors or employees that do access low use visitor areas can be informed, beforehand, of what to expect and to prepare accordingly.

Ticks

The ticks collected in 1999 and 2000 represented three genera and six species. Species collected were the lone star tick, Gulf Coast tick, American dog tick, rabbit tick (*Haemaphysalis leporispalustris*), deer tick, and *Ixodes dentatus*. However, not all life stages were collected for all of the species (Table 6). A total of 44,832 ticks were collected during the study. Of these, 99.6% consisted of lone star ticks (Table 6). Thus, all statistical analyses were focused on this species; all other species were excluded from analyses due to low numbers (Tables 6 and 7).

Although statistical analysis was not conducted on any of the other species, higher numbers of the American dog tick, rabbit tick, and deer tick were recorded in some of the months sampled (Table 7). More American dog tick adults were collected in July of 1999 than in any other month that year. This may indicate seasonal activity, the variability of this tick species by month, or other factors not identifiable due to insufficient numbers. Rabbit tick larvae were found in September and October of 1999 but not in any other month of either year (Table 7). One explanation for this occurrence may be that a plot was located next to a rabbit den. Numerically, more deer tick nymphs were collected in May (1999 and 2000) than in any other month (Table 7), possibly indicating spring occurrence. Although definite statements can not be made due to insufficient numbers, Schulze and others (1986) concluded that all life stages of the lone star tick coincided with those of the deer tick.

Mean numbers of lone star ticks, for all life stages combined, averaged over both years was 2.74 ticks/m^2. Adults made up 3.3% of the total (0.09 ticks/m^2) and nymphs constituted 20.9% (0.57 ticks/m^2). The vast majority of the total (75.9%) consisted of

Table 6. Number of ticks collected, estimated density (ticks/ha) by life stage and species percentage of totals at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999 and 2000.

Species	Life stage											
	Males		Females		Nymphs		Larvae		Total			
	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	Combined	% of total
Amblyomma americanum	247 (1822)	471 (3474)	262 (1932)	536 (3953)	2639 (19462)	6675 (49226)	15759 (116217)	18067 (133238)	18907 (139432)	25749 (189889)	44655 (329314)	99.60
Amblyomma maculatum	2 (15)	0 (0.00)	4 (30)	4 (30)	3 (22)	0 (0.00)	0 (0.00)	0 (0.00)	9 (66)	4 (30)	13 (96)	0.02
Dermacentor variabilis	12 (89)	5 (37)	13 (96)	5 (37)	0 (0.00)	3 (22)	0 (0.00)	3 (22)	25 (184)	16 (118)	41 (302)	0.09
Haemaphysalis leporispalustris	0 (0.00)	0 (0.00)	1 (7)	0 (0.00)	3 (22)	0 (0.00)	88 (649)	0 (0.00)	92 (679)	0 (0.00)	92 (679)	0.20
Ixodes dentatus	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	0 (0.00)	1 (7)	0 (0.00)	0 (0.00)	0 (0.00)	1 (7)	1 (7)	0.02
Ixodes scapularis	1 (7)	0 (0.00)	0 (0.00)	0 (0.00)	15 (111)	11 (81)	1 (7)	2 (15)	17 (125)	13 (96)	30 (221)	0.07
Total	262 (1932)	476 (3510)	279 (2058)	545 (4019)	2660 (19617)	6690 (49336)	15848 (116873)	18072 (133274)	19049 (140479)	25783 (190140)	44832 (330620)	100

Table 7. Number of ticks, excluding *Amblyomma americanum*, collected by month at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999 and 2000.

		May		June		July		Aug.		Sept.		Oct.	
Species	Lifestage	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Amblyomma maculatum	Males (adult)	1	0	0	0	1	0	0	0	0	0	0	0
	Females (adult)	0	1	2	0	1	2	1	1	0	0	0	0
	Nymphs	1	0	0	0	2	0	0	0	0	0	0	0
	Larvae	0	0	0	0	0	0	0	0	0	0	0	0
Dermacentor variabilis	Males (adult)	2	1	3	0	7	1	0	3	0	0	0	0
	Females (adult)	2	1	5	2	6	1	0	1	0	0	0	0
	Nymphs	0	3	0	0	0	0	0	0	0	0	0	0
	Larvae	0	3	0	0	0	0	0	0	0	0	0	0
Haemaphysalis leporispalustris	Males (adult)	0	0	0	0	0	0	0	0	0	0	0	0
	Females (adult)	0	0	1	0	0	0	0	0	0	0	0	0
	Nymphs	1	0	1	0	0	0	0	0	1	0	0	0
	Larvae	0	0	0	0	0	0	0	0	34	0	54	0
Ixodes dentatus	Males (adult)	0	0	0	0	0	0	0	0	0	0	0	0
	Females (adult)	0	0	0	0	0	0	0	0	0	0	0	0
	Nymphs	0	0	0	1	0	0	0	0	0	0	0	0
	Larvae	0	0	0	0	0	0	0	0	0	0	0	0
Ixodes scapularis	Males (adult)	0	0	0	0	0	0	0	0	0	0	1	0
	Females (adult)	0	0	0	0	0	0	0	0	0	0	0	0
	Nymphs	10	7	3	2	2	2	0	0	0	0	0	0
	Larvae	1	1	0	0	0	1	0	0	0	0	0	0

larvae (2.08 ticks/m^2). These densities are similar to those reported in the literature. Bloemer and others (1986) and Koch (1987) reported 6.5 to 54.3 ticks per hour of dry ice sampling, or 0.13 to 1.12 ticks/m^2 using Koch's (1987) estimate. Area-based flagged estimates have ranged from 0.1 to 321.0 ticks per 1000m^2 (Cully 1999) and 0.3 to 415.0m^2 (Semtner and others 1971a, Semtner and Hair 1973), which converts to approximately <0.01 to 18.95 ticks/m^2.

Significant differences in mean numbers of ticks per plot existed among both years and months as well as by year among vegetation types. These data produced large tables that can be found in the appendix (Tables A-1 through A-3). Important data in these tables was moved into figures to aid interpretation. During both years, all life stage totals, with the exception of larvae, were greatest in May and decreased thereafter (Figure 5). In 1999, larvae began increasing in June, peaked in July, and decreased thereafter with the exception of a slight resurgence in September (Figure 5). In 2000, larvae were present in May, decreased in June, dramatically increased in July and peaked in August. They began a decreasing trend thereafter (Figure 5). Previous studies report similar seasonal variations. Lancaster (1973) found that lone star tick abundance, all life stages combined, peaked in August, larvae possibly influenced values. Peaks in abundance of adult lone star ticks have been found to occur in May and June (Semtner and Hair 1973). Nymphs were also found to occur in peak numbers in May (Schulze and others 1984, Lavender and Oliver 1996). Larvae have been documented as occurring in peak numbers from August to September (Semtner and Hair 1973, Schulze and others 1984). Schulze and others (1986) concluded that all life stages of the lone star tick coincided with those of the deer tick. Park studies indicated that deer tick nymphs are most active in May

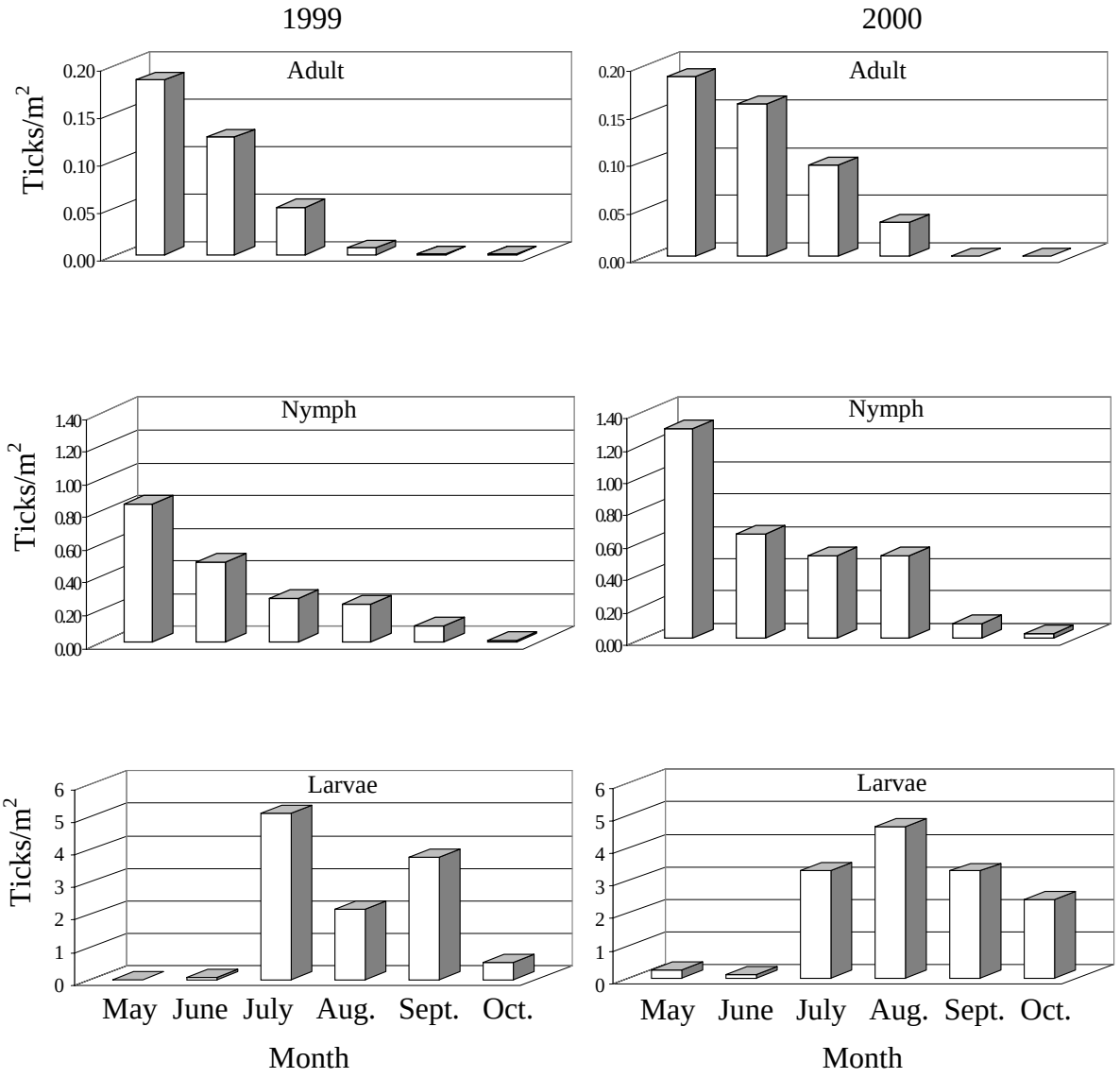

Figure 5. Average *Amblyomma americanum* density by lifestage and year over all vegetation types at Arkansas Post National Memorial, Arkansas County, Arkansas.

and June (Main and others 1982, Schulze and others 1984, Ginsberg 1992, Mannelli and others 1994), larvae from July to August (Main and others 1982, Schulze and others 1984, Wilson and Spielman 1985, Ginsberg 1992, Mannelli and others 1994), and adults from April to May, and/or October to November (Schulze and others 1984, Benach and others 1987, Wilson and others 1990, Ginsberg 1992).

Of the five high visitor use areas, the sweetgum and oak/pine vegetation types both contained the highest density of ticks in 1999 and 2000, the lowest occurred in the oak/mixed type in 1999 and in the oak/hickory type in 2000 (Figure 6). The vast majority of collected ticks were larvae (Table 6). High numbers of larvae have been associated with leaf litter (Semtner and others 1971a). Semtner and others (1971a) and Davidson and others (1994) found that those areas with greater than 25% cover of leaf litter produced an abundance of nymphs. They also found that leaf litter was desirable as overwintering habitat for larvae and nymphs and that if an area was burned, reductions in tick populations would occur due to reduced litter depth, thus decreasing desirable tick habitat. Both of these vegetation types, oak/pine and sweetgum, contained a mean litter coverage of 76-95% (Table 4), which would have provided the required overwintering habitat. Currently the Park collects leaves in the fall and then dumps them in selected areas in order to provide a "Park-like setting" for the visitors. Consequently, the leaves are suspected of providing overwintering habitat for ticks. Thus it seems reasonable that leaf piles should be removed from these areas.

Reported lone star tick habitat consists of brushy forest environments and their associated ecotones (Goddard 1997). This habitat is similar to that found in the oak/pine and sweetgum vegetation types and may be a contributing factor in existing tick

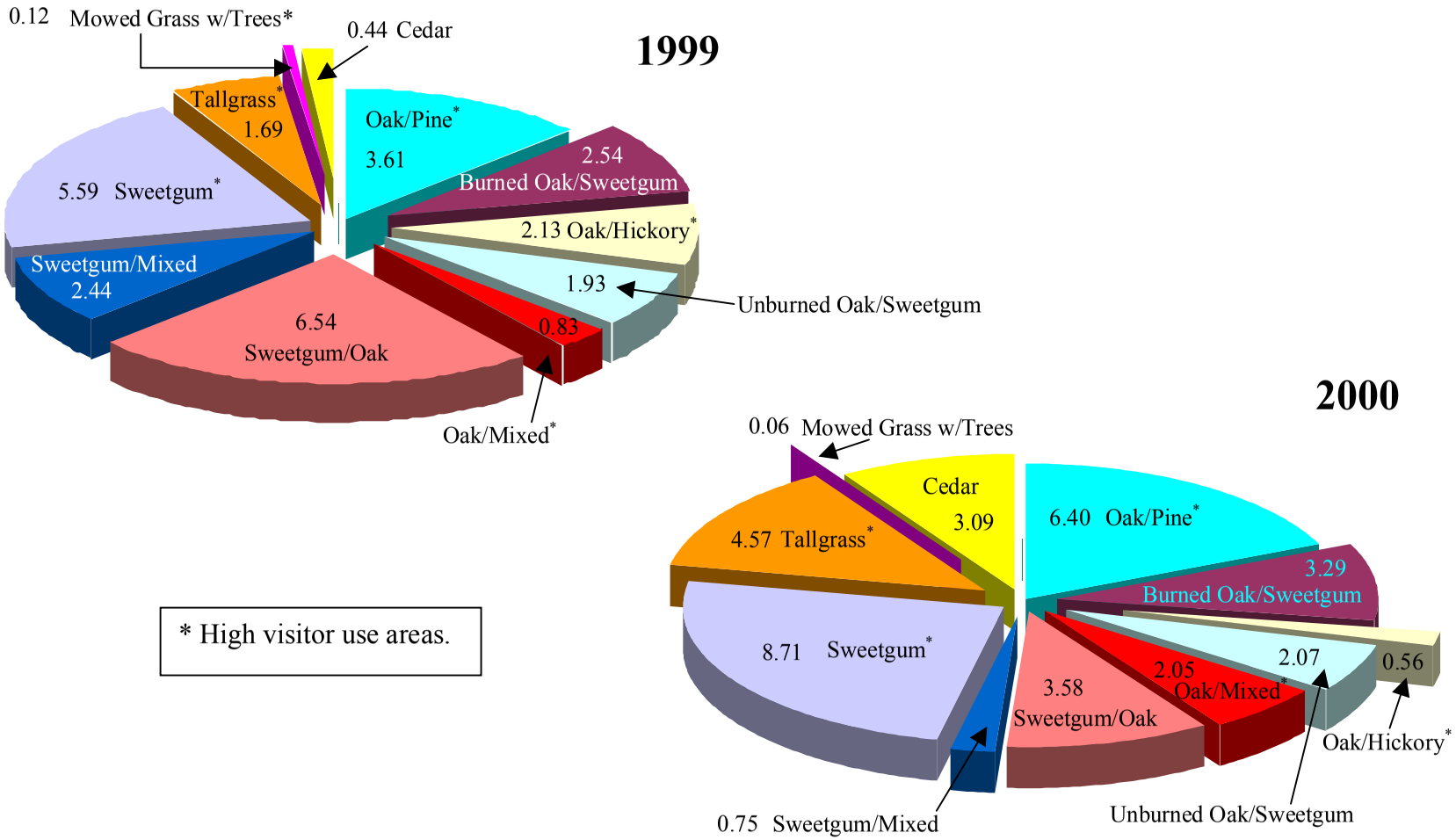

Figure 6. Mean *Amblyomma americanum* density (ticks/m^2) by vegetation type and year, all life stages combined, at Arkansas Post National Memorial, Arkansas County, Arkansas.

abundance. Another likely contributor to high tick numbers in these two types could be the moderate amount of vertical structure less than 1.5 meters high (approximately 25% mean percentage coverage) (Table 4). Semtner and others (1971a) reported that vegetation in grassy habitats that is 1.2m and shorter are important in producing ticks. Anecdotal evidence from an ongoing study suggests that white-tailed deer, a known host of the lone star tick (Pound and others 1996), is also suspected to heavily utilize these two areas.

ADULTS

Adults were numerically higher in the tallgrass, oak/pine and oak/mixed types than in other high visitor use areas in May, June, and July of 1999 (Figure 7). Within these vegetation types, adult numbers were highest in May and lowest in September and October (Figure 7). In 2000, adult numbers were higher in the oak/pine vegetation type than in any other high use area. Adults decreased after May and were lowest in September and October (Figure 7). Seasonal occurrence of adults, with the exception of August, was similar to reported findings (Lancaster 1973, Semtner and Hair 1973, Schulze and others 1986). High adult numbers in the oak/pine and oak/mixed types may be due to the high canopy cover (97%) found in each (Table 5), which agrees with reported findings (Lancaster 1973, Schulze and others 1986). However, percentage coverage of leaf litter (76-95%) did not agree with high adult tick numbers as reported by Semtner and others (1971a) (Table 5). High adult numbers found in the tallgrass area in May could be due to the high percentage of grass coverage, which would provide forage for white-tailed deer at this time of year. This may explain why adults were found in much lower abundance during other times of the year in this

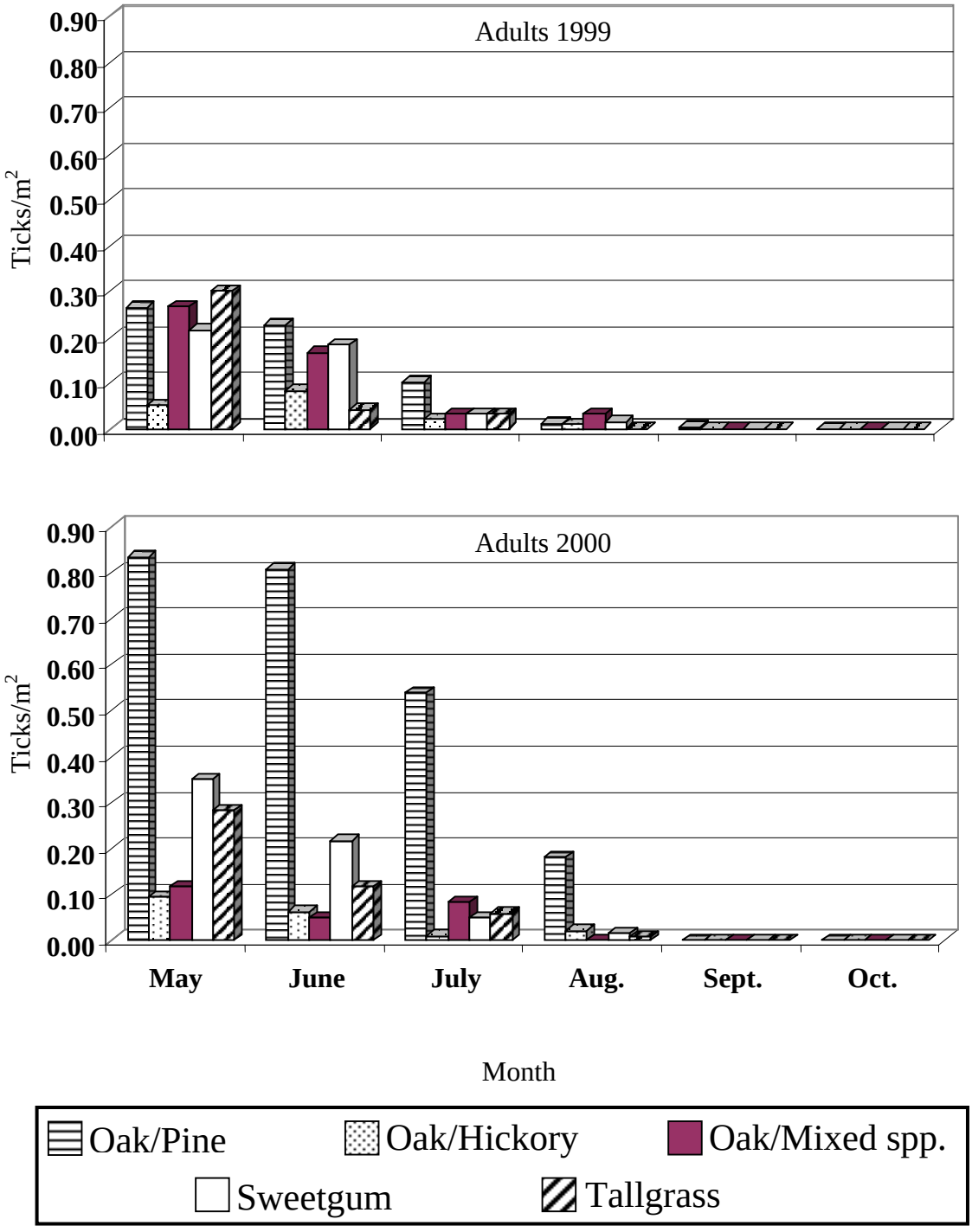

Figure 7. Average *Amblyomma americanum* adult density in high visitor use vegetation types, excluding the mowed areas, by month at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999 and 2000.

vegetation type. In May of 1999 and 2000, adults were lowest numerically in the oak/hickory type. In June of 1999 they were lowest in the tallgrass type; in 2000 they were lowest in the oak/mixed type (Figure 7). Low adult numbers may be due to the low percentage coverage of forbs (<50 %) in all three types, as well as the high percentage of leaf litter, excluding the tallgrass type (Table 5). Semtner and others (1971a) found that high populations of adult ticks were found in habitats where less than 25% of the ground was covered with leaf litter and when there was an occurrence of greater than 75% coverage of undergrowth vegetation. The tallgrass type contained a low percentage of canopy cover, which would have limited tick abundance due to low humidity and high heat. Open areas with little shade support fewer numbers of ticks (Schulze and others 1986). In addition, Sonenshine (1993) lists two principles that regulate lone star tick abundance, first a population of suitable hosts and second an area that conserves moisture through the presence of forest canopy.

It must be understood that ticks are a naturally occurring organism whose role in existing ecosystems at the Park has not yet been fully determined. However, if a reduction in tick abundance is necessary, then the adult life stage should be the focus of attention as this would reduce reproduction. Data from this study suggests that if adult population reduction is used, it should initially begin in the oak/pine, oak/mixed and tallgrass vegetation types in May and June.

Males and Females. In May, June, and July of 1999, adult males were lowest in the cedar, tallgrass, and oak/mixed spp. types, respectively (excluding the mowed areas). They were highest numerically in the sweetgum/mixed type in May and June and in the oak/pine type in July (Table A-1). The oak/pine vegetation type contained the highest

numbers of adult males in May, June and July of 2000 (Table A-1). The lowest numbers occurred in sweetgum/oak and cedar types in May and June and in the unburned oak/sweetgum and sweetgum types in July, excluding mowed areas.

In 1999, adult females were lowest in the cedar type in May, and the unburned oak/sweetgum type in June and July when the mowed areas are excluded. The highest adult female tick numbers in1999 occurred in the sweetgum/mixed spp. type in all three months (Table A-1). In 2000, the lowest numbers of female ticks, with mowed areas excluded, were in the oak/mixed spp. and sweetgum/oak types in May, the sweetgum/mixed type in June, and the sweetgum/mixed and cedar types in July (Table A-1). The highest number of females ticks in 2000 occurred in the oak/pine vegetation type in May, June and July. Discrepancies between vegetation types by year may be attributed to the natural variation of ticks within habitats as well as the distribution of ticks among them.

The literature does not distinguish between male and female adult preferences for habitats. In this study both males and females had their highest numbers in the sweetgum mixed and oak/pine types, though they occurred there in different months and in different years (Table A-1). This data suggest that there are no distinct habitat preferences among males and females.

NYMPHS

Nymphs were more abundant in the oak/pine type than in other high visitor use areas in May and July of 1999 (Figure 8). During the same year, nymphs were higher in the sweetgum type in June. The oak/pine type consistently contained more nymphs than any other type in 2000. Overall, factors contributing to high tick numbers in these two

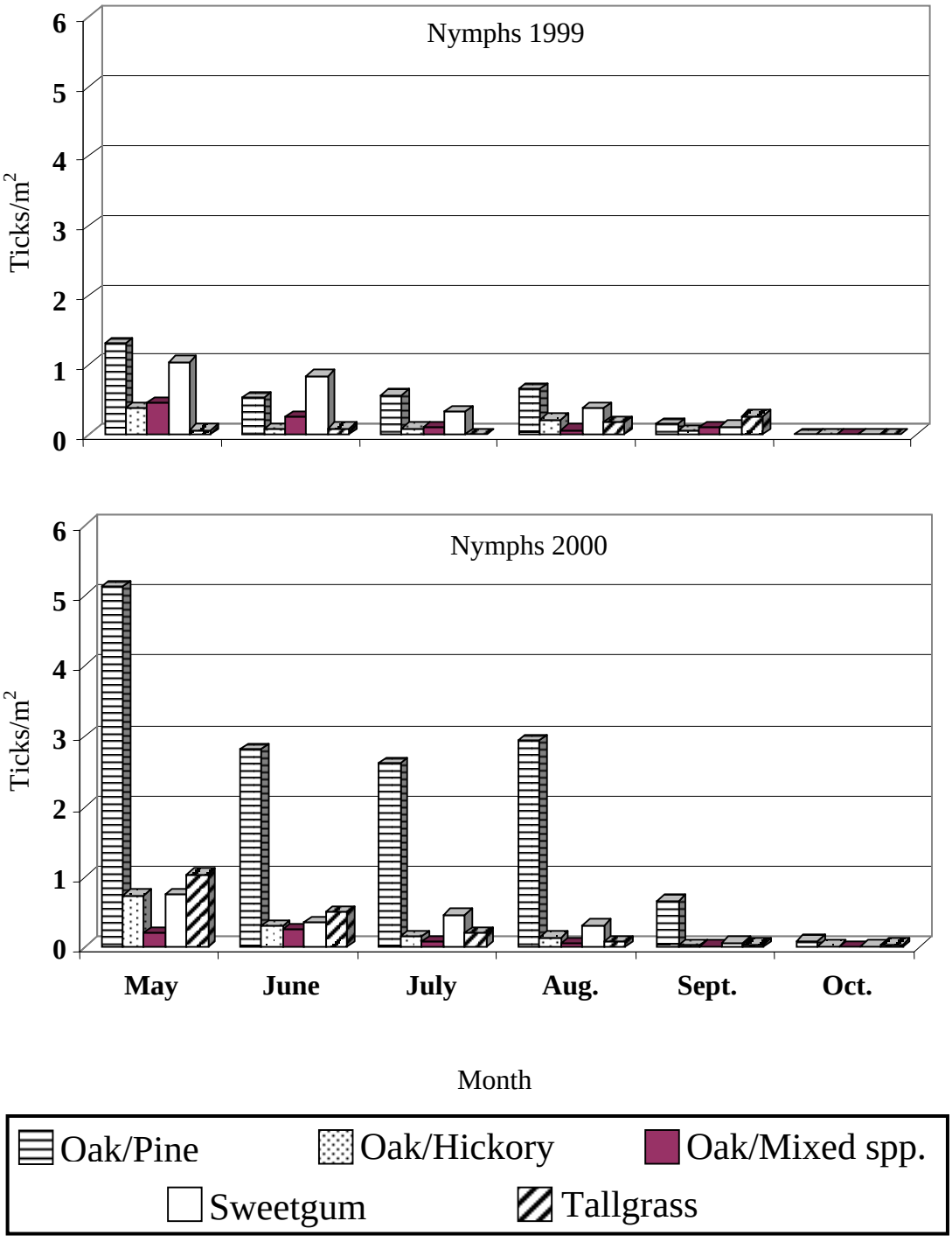

Figure 8. Mean *Amblyomma americanum* nymph density in high visitor use vegetation types, excluding the mowed areas, by month at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999 and 2000.

types may be the high percentages of leaf litter coverage (76-95%) and canopy cover (97%), the low percentage (6-25%) of forbs coverage (Table 5), and vertical structure less than 1.25m high (Table 4). Semtner and others (1971a) found that high populations of nymphs occurred when an area contained greater than 25% leaf litter coverage and when brushy vegetation was 25% or less. Lancaster (1973) states that lone star ticks cannot survive exposure to the sun, hence they are found in shaded areas. In 1999, low occurrences of nymphs (disregarding the mowed areas) in May, June, and July were found in the tallgrass area (Figure 8). In 2000, low occurrences of nymphs were recorded in the oak/mixed type during all months. Low numbers within these vegetation types may be due to their high percentage coverage of vertical structure 2.5m and less (Table 4). Thus, these areas may contain a large percentage of brushy vegetation that is lower than 2.5m. Semtner and others (1971a) found that lone star tick nymphs were found to occur in higher numbers in areas where brushy vegetation was 25% or less.

Because nymphs are small and hard to find on the body, they are the primary source of human infection (AFPM 1998, NPSb 1994). Consequently, they should be focused upon when a reduction of tick-borne disease risk is necessary. Thus, when a reduction in nymph abundance is the objective, focusing on the oak/pine and sweetgum types is imperative.

LARVAE

Larval numbers were highest in the sweetgum (1999) and tallgrass types (2000) in July than in any other high visitor use area (Figure 9). High numbers also occurred in the oak/pine and oak/hickory types (1999) and in the tallgrass type (2000) in August (Figure 9). The sweetgum type contained higher numbers than other high visitor use areas in

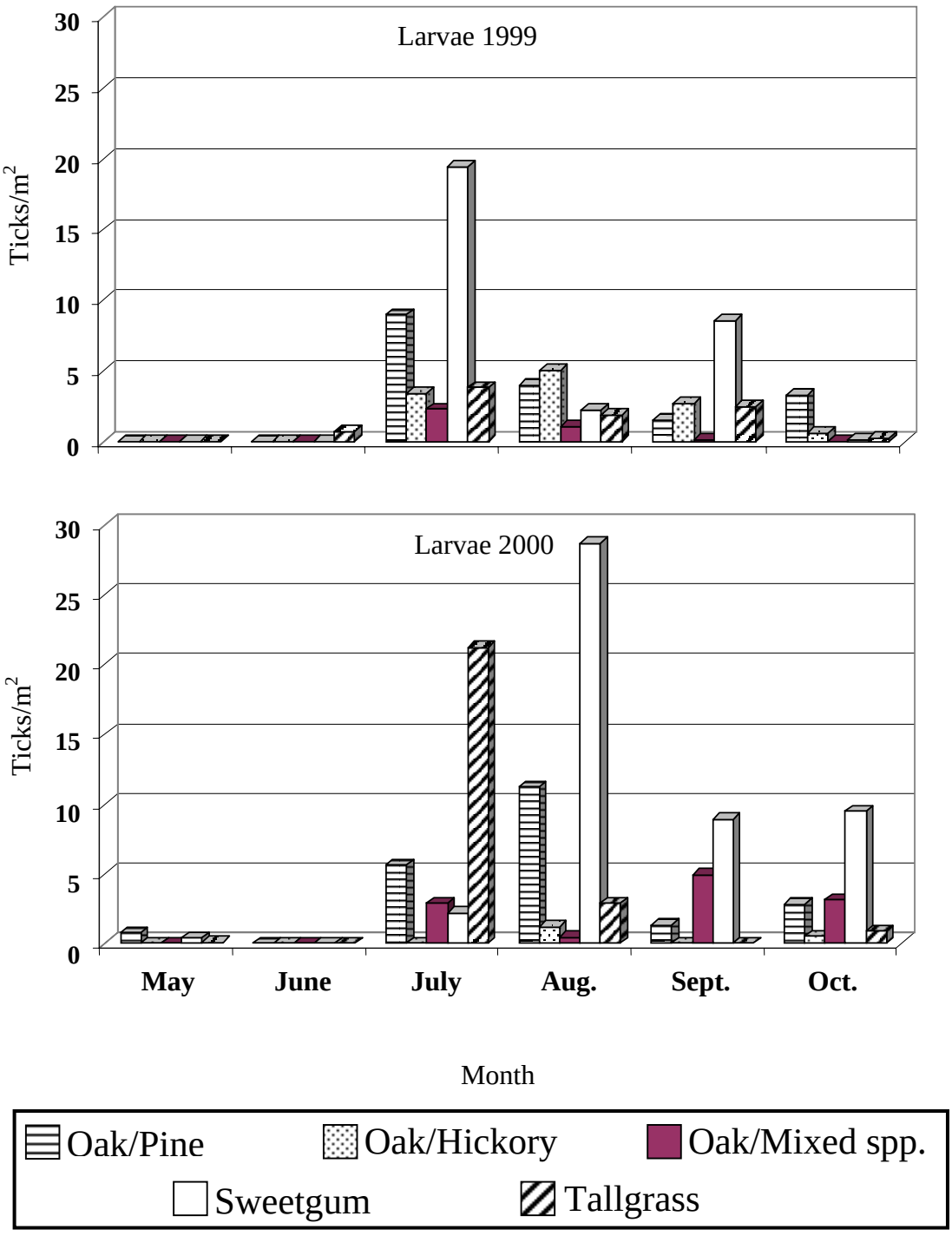

Figure 9. Mean *Amblyomma americanum* larval density in high visitor use vegetation types, excluding the mowed areas, by month at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999 and 2000.

September 1999 and 2000. The oak/pine (1999 and 2000), and oak/mixed and sweetgum (2000) types contained higher numbers of larva in October (Figure 9). Differences among tick numbers in vegetation types by month may be tied to their host's utilization of vegetation types, which would change depending upon what food source was temporally present. Anecdotal information suggests that these three types are associated with high white-tailed deer use as bedding, birthing, and/or feeding areas. Additionally, all three types contained a low percentage coverage of bare ground (Table 5). Thus, the necessary microhabitat and hosts for tick survival would have been present. However, larval tick survival is suspected to be low due to the low percentage of canopy cover in these areas, which would allow for higher temperatures and lower moisture during the hotter months of the year (Lancaster 1973). Hence, larval abundance within these vegetation types would be expected to be low. The lowest occurrence of larval numbers occurred in May and June of 1999 and 2000. In 1999, the oak/mixed type contained lower numbers in July, August, September, and October than in other high visitor use areas (Figure 9). In 2000, low numbers occurred in the oak/hickory and oak/mixed types in July and August. The oak/hickory and tallgrass types contained low numbers of larvae in September and October of 2000 (Figure 9). My vegetation data did not identify any biological differences between these three types that might have contributed to low larval tick numbers. Consequently, low tick numbers could be accredited to the natural variability of tick abundance among and/or within vegetation types, or other factors such as additional vegetative variables that were not measured in this study.

The oak/pine, sweetgum, and tallgrass types should be focused upon in July, and August if a decrease in larval abundance is the objective. An increase in visitor

satisfaction may result by reducing larvae; however, these reductions would have a minor effect on overall tick abundance as reproduction by adults would not be limited. Acaricide application is a popular method that is used to reduce ticks (Sonenshine 1993). However, if an acaricide is used, it should only be applied in areas where visitors are expected to remain for an extended period of time due to special events or camping activities. It is important to note that in these circumstances pesticides with residual effects are not necessary and therefore should not be used. Although kill on contact acaricides do not eliminate all ticks, as some will be "resting" within the available microhabitat or will be transported to the area via hosts, they should remove sufficient numbers to promote visitor and employee safety and satisfaction for an event. Because the ecological role ticks play at the Park has not yet been determined, the influence and role of white-tailed deer on tick density should also be considered when acaricides are used, as well as where special events are to be held within the Park.

Disease Assay

In 1999, 183 pooled samples of lone star ticks were analyzed for tick-borne diseases while 205 were analyzed in 2000. Total numbers of pooled samples analyzed by life stage each year were similar. There were 1132 ticks contained within the 1999 pooled samples and 1210 ticks in the 2000 samples (Table 8). Numbers analyzed between vegetation types varied and were dependent upon tick abundance within each type and year.

Neither Lyme disease nor HGE were detected in any of the pooled samples for either year. However HME was found in five pooled samples in 1999 and four in 2000. Two of the five pooled samples in 1999 did not contain positive tick singles. Four ticks

Table 8. Number of *Amblyomma americanum* tested for HGE, HME and Lyme disease by lifestage and vegetation type at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999 and 2000.

Vegetation Type	Year	Male	Female	Nymph	Total
Oak/Hickory[1]	1999	9	7	62	78
	2000	11	7	73	91
Oak/Pine[1]	1999	25	34	107	166
	2000	40	40	120	200
Oak/Mixed spp.[1]	1999	14	15	49	78
	2000	10	5	36	51
Burned Oak/Sweetgum	1999	24	18	94	136
	2000	30	36	90	156
Unburned Oak/Sweetgum	1999	15	13	79	107
	2000	23	34	88	145
Sweetgum[1]	1999	6	21	87	114
	2000	19	17	84	120
Sweetgum/Mixed	1999	24	31	89	144
	2000	13	18	91	122
Sweetgum Oak	1999	13	12	86	111
	2000	6	4	75	85
Cedar	1999	14	7	64	85
	2000	3	2	58	63
Mowed w/o trees[1]	1999	0	0	17	17
	2000	3	1	22	26
Mowed w/trees[1]	1999	0	0	7	7
	2000	0	4	27	31
Tallgrass[1]	1999	14	15	60	89
	2000	20	19	81	120
Total	1999	158	173	801	1132
	2000	178	187	845	1210

[1] High visitor use areas.

(0.4%) tested positive for HME within the other three pooled samples. Similarly, four ticks (0.3%) were found to be positive for HME within the 2000 pooled samples. Human monocytic ehrlichiosis was found in two adult male ticks and one nymph in the sweetgum type and in one nymph in the tallgrass type in 1999. HME was found in two nymphs in the unburned oak/sweetgum type and in one adult male and one nymph in the oak/pine type in 2000. Anecdotal evidence suggests that these four vegetation types may be heavily utilized by white-tailed deer, which have been implicated as host reservoirs for this disease (AFPM 1998, Brandsma and others 1999).

HGE was found in approximately 20% of collected deer ticks in New York (Daniels and others 1997). It occurred in 10% of the deer ticks collected in Wisconsin and in 50% of those collected in Connecticut (Walker 1996). Although HGE was not found at the Park, HME did occur in less than 1% of the ticks tested. Because of this, tick-borne disease frequency is considered to be low at the Park. Personal communications with Dennis Berry, epidemiologist, Arkansas State Health Department, and Melissa Miller, entomologist, USACHPPM-N support my conclusion that HME is present at low levels. As such, the best defense for disease awareness may be through interpretation, via educating the public and Park employees to take precautions and to avoid some areas.

CONCLUSIONS/RECOMENDATIONS

Tick populations are typically managed for two reasons: to reduce tick-borne disease risk or to reduce tick abundance. Different management approaches are required for each objective. Regardless of which objective is sought when managing ticks, seasonal occurrence, localities, and their associated vegetation characteristics are key factors in management (Figures 5, 6, 7, 8, and 9). All of these factors should be considered for either management objective so that problematic areas can be pinpointed and focused upon.

Due to their seasonality and low numbers, adult ticks should be the focus when the objective is to reduce tick abundance. By doing this, the next year's reproduction could be reduced. Information from this study indicates that in May in the high visitor use areas, adult tick abundance was higher in the oak/pine, oak/mixed and tallgrass types in 1999 and in the oak/pine, sweetgum and tallgrass types in 2000 (Figure 7). The oak/pine and sweetgum vegetation types contain higher overall numbers than other high visitor use areas (Figure 6).

An immediate increase in visitor satisfaction may be achieved if larvae were to be managed to reduce tick abundance. Larvae were more abundant in July and September in 1999 and in August of 2000 (Figure 9) in the sweetgum type than in any of the other high visitor use areas. The lowest numbers of larval ticks occurred in mowed areas.

Nymphs are the primary source of human infection due to their size (NPSb 1994, AFPM 1998). Hence, they should be the focus if tick-borne disease reduction is the primary objective. Nymphs were very abundant in the oak/pine and sweetgum vegetation types (Figure 8) in May, June, July and August.

This study shows that tick numbers at ARPO, although perceived to be numerous by Park visitors, are similar to those reported in the literature. Fortunately, there is a slight occurrence of tick-borne disease. Thus, a long-term monitoring regime needs to be established that will document the occurrence and estimated relative abundance of ticks over time. This regime could incorporate the methodologies used in this study or other methods could be developed. However, prior to initiation of any management regime it is recommended that the following activities and suggestions be considered:

1) Information provided in this study should only be used as a baseline since tick numbers and host use may vary among and within vegetation types.
2) Before any long-term monitoring regime is established, the Park administration needs to determine its goals, what defensible tick density or disease frequency thresholds will be used, and where they are applicable.
3) It must be understood that ticks are a naturally occurring organism whose role in existing ecosystems at the Park has not yet been determined.
4) Current mowing regimes have significantly reduced tick abundance in the mowed areas. These areas constitute the vast majority of high visitor use areas within the Park. Consequently, further tick reduction techniques may not be needed in these areas.
5) Although initially thought otherwise, tick-borne disease frequency is low at the Park. As such, the best defense may be through interpretation, via educating the public and Park employees to take precautions and to avoid some areas.

6) The sweetgum, oak/pine, and tallgrass types contained high numbers of ticks and are high visitor use areas. Therefore they should be included in any management and monitoring program.

7) Management techniques may include vegetative reduction (e.g., mowing, burning, and tree removal) and acaricide application, in appropriate areas, as determined by Park administrators.

8) If an acaricide is used, it should only be applied to areas of high visitor use and then limited to where visitors are expected to remain for an extended period due to special events or camping activities. It is important to note that in these circumstances pesticides with long-lasting effects are not necessary and therefore should not be used. Although kill-on-contact acaricides do not eliminate all ticks, as some will be "resting" within the available microhabitat or will be transported to the area via hosts, it should remove sufficient numbers to promote visitor and employ safety and satisfaction for the event. Limitations on the type and amount of acaricide as well as locations of application must be determined beforehand; NPS Integrated Pest Management, as well as other applicable NPS protocols can assist in this determination.

9) The influence of white-tailed deer on tick density should be considered in any management regime where acaricides are used (e.g., four-poster application systems) as deer are suspected of contributing in large part to the tick density at the Park.

10) Acaricides can additionally be used to reduce the number of ticks on small mammal hosts, via application to nesting materials such as permethrin-laced

cotton-balls made available for mice to use as a nesting material. Thus, reducing specific life stages, which in time should reduce tick numbers overall. This technique has been applied to other study areas, with some success in the reducing tick numbers (Deblinger and Rimmer 1991).

11) Prescribed fire can be utilized in applicable areas like the tallgrass vegetation type. Annual and biennial burns have been shown to drastically reduce tick abundance (Davidson and others 1994). Fire regimes with burn frequencies of more than three years should not be used. Tick abundance has been shown to increase exponentially as burning frequency decreases (Sonenshine 1993). Because fire periodicity in wooded areas of the Park should consist of burn frequencies of at least 5 to 10 years, forested areas should not be managed with fire simply to reduce tick abundance.

12) Low visitor use areas should be excluded from consideration of either objective as visitors and employees do not normally access these areas. Visitors, or employees, who do access these areas should be informed, beforehand, of what to expect and prepare accordingly.

13) Currently, leaves are collected in the fall and then dumped in selected areas around the Park to provide a park like setting for the visitors. However, leaf litter piles should not be placed in areas of high visitor use (e.g., around the picnic area, maintenance yard, and parking lots and along trail edges) because leaf litter is an important component of tick abundance (Semtner and others 1971a, Davidson and others 1994). As such, existing leaf piles are suspected of providing prime habitat

for ticks, and their associated small to medium sized mammal hosts. Hence, they should be removed from these areas.

14) Brush should be removed or thinned from high visitor use areas and/or around residential areas in an attempt to reduce available habitat, thus reducing the occurrence of host mammals.

Further studies need to be completed, in conjunction with monitoring regimes, to determine the ecological role ticks and their hosts play at the Park, as well as which vegetative component(s) are pertinent to tick survival. This information will compliment and enhance this study and will provide additional information for tick density and/or tick-borne disease reduction.

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APPENDIX

Table A-1. Mean number of *Amblyomma americanum* ticks collected per 2m x 6m plot by lifestage and vegetation type at Arkansas Post National Memorial, Arkansas County, Arkansas.

Lifestage	Vegetation Type	May		June		July		Aug.		Sept.		Oct.	
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Adults	Oak/Hickory[1]	0.63 b[2] (0.26)	1.13 bf (0.48)	1.00 bcf (0.46)	0.75 bcf (0.25)	0.25 bcef (0.16)	0.13 cg (0.13)	0.13 (0.13)	0.25 bc (0.25)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Oak/Pine[1]	3.18 a (0.96)	10.00 ae (4.84)	2.73A[3]af (1.26)	9.68Ba (3.54)	1.23Aa (0.44)	6.45Ba (1.68)	0.14A (0.07)	2.18Ba (0.77)	0.05 (0.05)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Oak/mixed spp.[1]	3.20 c (1.28)	1.40 ae (0.24)	2.00 d (0.55)	0.60 ce (0.40)	0.40 be (0.24)	1.00 de (0.45)	0.40 (0.24)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Burned Oak/ Sweetgum	2.00 a (0.75)	2.50 ab (1.22)	1.42 abf (0.53)	3.83 ad (1.25)	0.33Abe (0.14)	2.00Bb (0.60)	0.17 (0.17)	0.67 bd (0.40)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Unburned Oak/ Sweetgum	0.88 b (0.35)	3.06 b (2.15)	0.56 c (0.18)	1.81 bd (0.52)	0.06 cef (0.06)	0.44 ce (0.18)	0.00A (0.00)	0.63Bb (0.30)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum[1]	2.60 ac (0.93)	4.20 d (1.59)	2.20 df (0.86)	2.60 d (1.03)	0.40 be (0.24)	0.60 cfg (0.60)	0.20 (0.20)	0.20 bc (0.20)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum/ Mixed	8.63 ac (5.27)	0.88 bf (0.30)	4.13 d (1.46)	1.38 bcd (0.53)	2.38 d (0.84)	0.88 df (0.35)	0.00 A (0.00)	0.75Ba (0.25)	0.00 (0.00)	0.00 (0.00)	0.13 (0.13)	0.00 (0.00)
	Sweetgum/ Oak	2.00Aac (.071)	0.00Bc (0.00)	1.80 df (0.49)	0.60 ce (0.40)	1.20 d (0.37)	1.00 ef (0.77)	0.00 (0.00)	0.40 bc (0.40)	0.00 (0.00)	0.00 (0.00)	0.20 (0.20)	0.00 (0.00)
	Cedar	0.00 d (0.00)	0.00 c (0.00)	1.60 f (0.93)	0.40 efg (0.40)	0.60 abg (0.40)	0.60 cdf (0.40)	0.00 (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mowed w/o trees	0.00 d (0.00)	0.50 f (0.27)	0.00 e (0.00)	0.00 g (0.00)	0.00 f (0.00)	0.00 g (0.00)	0.00 (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mowed w/trees	0.00 d (0.00)	0.22 cf (0.15)	0.00 e (0.00)	0.11 eg (0.11)	0.00 f (0.00)	0.11 cg (0.11)	0.00 (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Table A-1. Continued

Lifestage	Vegetation Type	May		June		July		Aug.		Sept.		Oct.	
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Adults	Tallgrass[1]	3.60 ac (1.49)	3.40 e (1.18)	0.50 c (0.22)	1.40 cf (0.67)	0.40 efg (0.31)	0.70 cdf (0.42)	0.00 (0.00)	0.10 cd (0.10)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Males (adult)	Oak/Hickory[1]	0.38 bd (0.18)	0.50 bd (0.38)	0.63 ac (0.38)	0.38 bc (0.18)	0.13 b (0.13)	0.13 cd (0.13)	0.00 (0.00)	0.13 b (0.13)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Oak/Pine[1]	1.95 ae (0.69)	4.68 a (2.01)	1.32 a (0.64)	4.45 a (1.70)	0.77 Aa (0.35)	3.00Ba (0.92)	0.00 A (0.00)	0.86Ba (0.27)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Oak/mixed spp.[1]	1.80 ace (0.92)	1.40 c (0.24)	1.00 b (0.32)	0.40 bc (0.24)	0.00 b (0.00)	0.20 bcd (0.20)	0.00 (0.00)	0.00 b (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Burned Oak/ Sweetgum	1.00 ade (0.35)	1.25 b (0.76)	0.83 ac (0.34)	1.75 a (0.48)	0.17 b (0.11)	0.67 bd (0.26)	0.17 (0.17)	0.17 b (0.11)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Unburned Oak/ Sweetgum	0.38 bdg (0.18)	1.38 b (0.93)	0.50 ac (0.16)	0.94 b (0.31)	0.06 b (0.06)	0.00 c (0.00)	0.00 (0.00)	0.19 b (0.14)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum[1]	0.60 d (0.40)	2.40 c (0.81)	0.40 c (0.24)	1.60 a (0.68)	0.20 b (0.20)	0.00 ce (0.00)	0.00 (0.00)	0.20 b (0.20)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum/ Mixed	3.50 acde (2.24)	0.38 b (0.18)	2.00 Ab (0.85)	0.25Bce (0.25)	0.63 c (0.26)	0.50 d (0.27)	0.00 (0.00)	0.13 b (0.13)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum/ Oak	1.60Ace (0.51)	0.00Bde (0.00)	1.00 b (0.32)	0.20 cde (0.20)	0.60 c (0.24)	0.80 bd (0.58)	0.00 (0.00)	0.20 b (0.20)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Cedar	0.00 gh (0.00)	0.00 de (0.00)	0.60 ac (0.40)	0.20 cef (0.20)	0.20 b (0.20)	0.40 bcd (0.40)	0.00 (0.00)	0.00 b (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mowed w/o trees	0.00 h (0.00)	0.38 be (0.26)	0.00 e (0.00)	0.00 e (0.00)	0.00 b (0.00)	0.00 ce (0.00)	0.00 (0.00)	0.00 b (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Table A-1. Continued

Lifestage	Vegetation Type	May		June		July		Aug.		Sept.		Oct.	
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Males (adult)	Mowed w/trees	0.00 fh (0.00)	0.00 e (0.00)	0.00 de (0.00)	0.00 e (0.00)	0.00 b (0.00)	0.00 ce (0.00)	0.00 (0.00)	0.00 b (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Tallgrass[1]	1.50 e (0.52)	2.70 ac (1.01)	0.30 c (0.15)	0.60 bdf (0.27)	0.10 b (0.10)	0.40 de (0.27)	0.00 (0.00)	0.00 b (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Females (adult)	Oak/Hickory[1]	0.25 bc (0.16)	0.63 bcf (0.32)	0.38 bc (0.26)	0.38 cdf (0.18)	0.13 bc (0.13)	0.00 c (0.00)	0.13 (0.13)	0.13 bc (0.13)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Oak/Pine[1]	1.23 ae (0.33)	5.32 a (2.85)	1.41 Aa (0.64)	5.23Ba (1.87)	0.45 Aac (0.18)	3.45Ba (0.80)	0.14A (0.07)	1.32Ba (0.59)	0.05 (0.05)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Oak/mixed spp.[1]	1.40Ad (0.40)	0.00Bd (0.00)	1.00 ae (0.55)	0.20 dfg (0.20)	0.40 cd (0.24)	0.80 bd (0.37)	0.40 (0.24)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Burned Oak/ Sweetgum	1.00 ace (0.44)	1.25 abe (0.54)	0.58 ab (0.29)	2.08 b (0.87)	0.17Aabcd (0.11)	1.33Bb (0.51)	0.00 (0.00)	0.50 abe (0.29)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Unburned Oak/ Sweetgum	0.50 c (0.22)	1.69 cf (1.24)	0.06 Acf (0.06)	0.88Bbc (0.35)	0.00Ab (0.00)	0.44Bde (0.18)	0.00A (0.00)	0.44Bbd (0.20)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum[1]	2.00 d (0.84)	1.80 e (0.86)	1.80 eg (0.73)	1.00 be (0.45)	0.20 abcd (0.20)	0.60 cd (0.60)	0.20 (0.20)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Sweetgum/ Mixed	5.13 de (3.04)	0.50 bcfg (0.27)	2.13 de (0.77)	1.13 b (0.40)	1.75 e (0.70)	0.38 de (0.18)	0.00A (0.00)	0.63Bad (0.26)	0.00 (0.00)	0.00 (0.00)	0.13 (0.13)	0.00 (0.00)
	Sweetgum/ Oak	0.40 cf (0.40)	0.00 d (0.00)	0.80 ae (0.37)	0.40 cdef (0.24)	0.60 de (0.40)	0.20 ce (0.20)	0.00 (0.00)	0.20 bc (0.20)	0.00 (0.00)	0.00 (0.00)	0.20 (0.20)	0.00 (0.00)
	Cedar	0.00 bf (0.00)	0.00 d (0.00)	1.00 ag (0.55)	0.20 dfg (0.20)	0.40 abcd (0.40)	0.20 ce (0.20)	0.00 (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

Table A-1. Continued

Lifestage	Vegetation Type	May		June		July		Aug.		Sept.		Oct.	
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Females (adult)	Mowed w/o trees	0.00 bf (0.00)	0.13 dg (0.13)	0.00 cf (0.00)	0.00 g (0.00)	0.00 bf (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Mowed w/trees	0.00 bf (0.00)	0.22 df (0.15)	0.00 f (0.00)	0.11 fg (0.11)	0.00 bf (0.00)	0.11 ce (0.11)	0.00 (0.00)	0.00 c (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Tallgrass[1]	2.10 e (1.11)	0.70 bc (0.30)	0.20 cf (0.20)	0.80 cde (0.47)	0.30 acdf (0.21)	0.30 ce (0.21)	0.00 (0.00)	0.10 ce (0.10)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Nymphs	Oak/Hickory[1]	4.50 bc (0.85)	8.88 bc (5.79)	1.00 b (0.50)	3.63 bf (1.74)	1.13 b (0.40)	1.88 c (1.09)	2.63 bf (1.13)	1.63 b (0.32)	0.63 (0.32)	0.38 bd (0.18)	0.00 (0.00)	0.25 (0.25)
	Oak/Pine[1]	15.77 a (5.00)	61.45 ac (31.85)	6.32 a (1.31)	33.82 a (13.02)	6.82 a (1.89)	31.32 ad (11.92)	7.86 a (2.18)	35.23 a (11.90)	1.86 (0.51)	8.00 ac (3.93)	0.09 A (0.09)	1.14 B (0.45)
	Oak/mixed spp.[1]	5.40 c (0.75)	2.40 bf (1.12)	3.00 c (1.45)	3.00 bd (1.34)	1.20 bd (0.37)	1.00 c (0.45)	0.80 deh (0.58)	0.60 cf (0.40)	1.20 (0.80)	0.20 be (0.20)	0.00 (0.00)	0.00 (0.00)
	Burned Oak/ Sweetgum	11.00 ac (3.32)	26.17 bc (18.52)	5.08 ac (2.06)	8.50 ac (3.76)	4.75 ac (2.14)	9.00 bd (4.59)	1.17 bd (0.34)	6.33 bd (2.81)	1.33 (0.40)	0.67 bd (0.33)	0.00 (0.00)	0.17 (0.11)
	Unburned Oak/ Sweetgum	6.06 bc (1.56)	50.44 bc (45.85)	4.00 c (1.11)	19.56 cd (10.09)	3.06 cd (0.98)	4.00 b (1.39)	0.63Acdh (0.26)	7.63Bbd (4.13)	0.50 (0.20)	0.38 bd (0.13)	0.06 (0.06)	0.13 (0.09)
	Sweetgum[1]	12.60 d (2.23)	9.00 d (2.28)	10.20A e (2.35)	4.20 cdf (1.32)	4.00 ac (1.64)	5.60 adeg (2.20)	4.60 gi (0.60)	3.80 bd (1.36)	1.40 (0.93)	0.80 acd (0.37)	0.00 (0.00)	0.20 (0.20)
	Sweetgum/ Mixed	41.00Ad (28.81)	5.50Bce (1.65)	15.13Ad (2.46)	8.50Be (2.04)	7.38 e (1.08)	8.25 e (1.75)	2.38Aafi (0.84)	10.38Be (2.99)	1.00 (0.73)	1.13 cf (0.48)	0.13 (0.13)	0.25 (0.16)
	Sweetgum/ Oak	17.60Ad (5.88)	4.80Bbc (2.82)	18.20 de (8.06)	1.60 bg (0.51)	7.80 acd (5.64)	6.60 deg (3.14)	5.40 bef (4.43)	4.40 d (1.57)	1.00 (0.55)	0.80 bc (0.58)	0.20 (0.20)	0.60 (0.40)

Table A-1. Continued

Lifestage	Vegetation Type	May		June		July		Aug.		Sept.		Oct.	
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Nymphs	Cedar	4.40Abc (0.60)	0.80Bg (0.58)	6.40 e (1.60)	3.60 acde (0.60)	1.60 bc (0.51)	3.20 bg (1.02)	4.60 i (1.29)	2.40 bd (0.81)	1.20A (0.58)	0.60Abdf (0.40)	0.00 (0.00)	0.60 (0.40)
	Mowed w/o trees	0.38 e (0.18)	2.63 fg (2.21)	0.00 f (0.00)	0.25 h (0.16)	0.00 f (0.00)	0.00 f (0.00)	0.38 h (0.26)	0.00 f (0.00)	0.00 (0.00)	0.00 e (0.00)	0.00 (0.00)	0.00 (0.00)
	Mowed w/trees	1.67 e (1.30)	2.22 fg (1.18)	0.11 bf (0.11)	0.78 gh (0.43)	0.00 f (0.00)	0.11 f (0.11)	0.22 h (0.15)	0.00 f (0.00)	0.11 (0.11)	0.00 e (0.00)	0.00 (0.00)	0.00 (0.00)
	Tallgrass[1]	0.80Ae (0.53)	12.50Bbe (6.63)	1.10 b (0.46)	6.00 cdf (2.43)	0.10Af (0.10)	2.50Bc (1.25)	2.20 bcd (1.45)	1.00 c (0.45)	3.20 (2.76)	0.50 bd (0.22)	0.00 A (0.00)	0.50 B (0.22)
Larvae	Oak/Hickory[1]	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	40.88Aabdf (26.09)	0.25 Ba (0.25)	60.88 (57.47)	14.75 bc (12.94)	32.25 ac (30.16)	0.00 b (0.00)	7.50 ac (3.96)	6.13 cd (2.07)
	Oak/Pine[1]	0.00 (0.00)	9.05 (8.86)	0.00 (0.00)	0.00 (0.00)	107.59 a (48.05)	67.55 a (31.92)	48.18 (18.52)	134.77 ac (56.18)	18.73 a (15.09)	16.32 a (8.88)	39.59 a (26.33)	33.77 ad (12.30)
	Oak/mixed spp.[1]	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	27.40 abd (15.02)	35.00 a (35.00)	13.20 (7.26)	5.40 ce (3.44)	1.40 cf (0.93)	59.40 cd (37.89)	0.40 b (0.40)	37.40 ac (26.55)
	Burned Oak/ Sweetgum	0.00 (0.00)	0.00 (0.00)	3.50 (2.44)	16.67 (16.58)	15.67 bdf (7.37)	48.92 a (30.68)	122.42 (69.27)	99.50 ac (44.35)	13.50Abc (7.51)	5.00 Bab (5.00)	0.25 b (0.13)	6.67 b (4.66)
	Unburned Oak/ Sweetgum	0.00 (0.00)	7.94 (7.61)	0.00 (0.00)	0.00 (0.00)	23.06Aab (15.79)	0.63 Ba (0.46)	7.81 (6.63)	26.44 bf (19.53)	73.38Abc (49.08)	25.00 Babc (21.98)	18.63Aac (13.43)	1.31Bb (1.31)
	Sweetgum[1]	0.00 (0.00)	4.40 (4.40)	0.00 (0.00)	0.00 (0.00)	233.60 c (160.02)	26.60 a (21.73)	26.80A (24.32)	343.80Bd (111.74)	102.80 e (82.84)	107.20 cd (66.85)	1.40 ac (0.68)	114.00 cf (67.03)
	Sweetgum/ Mixed	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	37.50 df (35.65)	10.50 a (10.36)	0.13 (0.13)	2.25 bf (2.25)	53.88Abd (38.44)	0.00 Bb (0.00)	2.00 c (1.18)	3.13 be (3.13)

Table A-1. Continued

Lifestage	Vegetation Type	May		June		July		Aug.		Sept.		Oct.	
		1999	2000	1999	2000	1999	2000	1999	2000	1999	2000	1999	2000
Larvae	Sweetgum/ Oak	0.00 (0.00)	12.60 (12.60)	0.00 (0.00)	0.00 (0.00)	202.20 c (110.32)	32.20 a (32.20)	0.40 (0.40)	9.20 bf (9.20)	210.20 de (198.27)	152.40 d (16.92)	2.80 a (0.80)	30.60 de (30.60)
	Cedar	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	2.00Af (0.84)	0.00 Ba (0.00)	5.20A (2.31)	0.00Bf (0.00)	2.00 af (1.38)	107.00 cd (82.30)	1.80 ac (0.58)	103.40 f (37.18)
	Mowed w/o trees	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.25 (0.16)	0.00 e (0.00)	0.00 a (0.00)	1.88 (1.13)	0.00 f (0.00)	0.00 g (0.00)	0.00 b (0.00)	0.00 b (0.00)	0.00 be (0.00)
	Mowed w/trees	0.00 (0.00)	0.11 (0.11)	0.00 (0.00)	0.22 (0.22)	0.22 e (0.22)	0.22 a (0.22)	2.67 (1.45)	0.44 bf (0.34)	3.33 af (1.96)	0.00 b (0.00)	0.00 b (0.00)	0.00 be (0.00)
	Tallgrass[1]	0.00 (0.00)	0.80 (0.51)	8.40 (8.40)	0.00 (0.00)	45.60 c (12.64)	254.60 a (179.78)	23.00 (12.53)	34.30 be (21.44)	29.90Acf (19.62)	0.00 Bb (0.00)	3.10 ac (1.21)	10.60 be (10.60)
Adults	All Types Combined	2.27 (0.48)	3.39 (1.04)	1.50 (0.30)	3.02 (0.77)	0.62A (0.13)	1.81B (0.40)	0.08A (0.03)	0.69B (0.18)	0.01 (0.01)	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)
Males (adult)	All Types Combined	1.12 (0.23)	1.73 (0.45)	0.76 (0.15)	1.39 (0.37)	0.28 (0.08)	0.80 (0.21)	0.02A (0.02)	0.25B (0.06)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Females (adult)	All Types Combined	1.15 (0.27)	1.65 (0.60)	0.74 (0.16)	1.63 (0.41)	0.34A (0.08)	1.02B (0.21)	0.06A (0.02)	0.44B (0.13)	0.01 (0.01)	0.00 (0.00)	0.02 (0.01)	0.00 (0.00)
Nymphs	All Types Combined	10.32 (2.40)	25.12 (9.28)	5.26 (0.70)	12.27 (3.11)	3.52A (0.57)	9.29B (2.57)	3.02A (0.55)	10.04B (2.66)	1.19 (0.28)	1.94 (0.80)	0.04A (0.02)	0.40B (0.10)
Larvae	All Types Combined	0.00A (0.00)	3.72B (2.10)	1.12 (0.79)	1.81 (1.76)	56.06A (13.93)	45.89B (18.04)	32.20 (9.61)	60.68 (14.96)	38.48A (12.65)	26.10B (8.08)	11.60A (5.55)	21.69B (5.17)

[1] Forested high visitor use areas.

[2] Lowercase letters that are the same within a column by lifestage indicate no difference (p-value ≥0.05).

[3] Uppercase letters that are different within a row by lifestage and month indicate no difference (p-value ≥0.05).

Table A-2. Mean number of *Amblyomma americanum* ticks collected per 2m x 6m plot at Arkansas Post National Memorial, Arkansas County, Arkansas, 1999.

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Oak/Hickory[1]	Adults	0.63a[2]	1.00a	0.25b	0.13b	0.00b	0.00b
		(0.26)	(0.46)	(0.16)	(0.13)	(0.00)	(0.00)
	Male	0.38	0.63	0.13	0.00	0.00	0.00
	(adult)	(0.18)	(0.38)	(0.13)	(0.00)	(0.00)	(0.00)
	Female	0.25	0.38	0.13	0.13	0.00	0.00
	(adult)	(0.16)	(0.26)	(0.13)	(0.13)	(0.00)	(0.00)
	Nymph	4.50a	1.00bc	1.13bc	2.63b	0.63cd	0.00d
		(0.85)	(0.50)	(0.40)	(1.13)	(0.32)	(0.00)
	Larvae	0.00a	0.00a	40.88bd	60.88cd	32.25c	7.50d
		(0.00)	(0.00)	(26.09)	(57.47)	(30.16)	(3.96)
Oak/Pine[1]	Adults	3.18a	2.73b	1.23c	0.14d	0.05d	0.00d
		(0.96)	(1.26)	(0.44)	(0.07)	(0.05)	(0.00)
	Male	1.95a	1.32b	0.77b	0.00c	0.00c	0.00c
	(adult)	(0.69)	(0.64)	(0.35)	(0.00)	(0.00)	(0.00)
	Female	1.23a	1.41a	0.45b	0.14c	0.05c	0.00c
	(adult)	(0.33)	(0.64)	(0.18)	(0.07)	(0.05)	(0.00)
	Nymph	15.77a	6.32b	6.82b	7.86b	1.86c	0.09d
		(5.00)	(1.31)	(1.89)	(2.18)	(0.51)	(0.09)
	Larvae	0.00a	0.00a	107.59b	48.18b	18.73c	39.59b
		(0.00)	(0.00)	(48.05)	(18.52)	(15.09)	(26.33)

Table A-2. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Oak/mixed spp.[1]	Adults	3.20a	2.00a	0.40b	0.40b	0.00c	0.00c
		(1.28)	(0.55)	(0.24)	(0.24)	(0.00)	(0.00)
	Male	1.80a	1.00a	0.00b	0.00b	0.00b	0.00b
	(adult)	(0.92)	(0.32)	(0.00)	(0.00)	(0.00)	(0.00)
	Female	1.40a	1.00b	0.40b	0.40b	0.00c	0.00c
	(adult)	(0.40)	(0.55)	(0.24)	(0.24)	(0.00)	(0.00)
	Nymph	5.40a	3.00b	1.20bc	0.80c	1.20c	0.00d
		(0.75)	(1.45)	(0.37)	(0.58)	(0.80)	(0.00)
	Larvae	0.00ad	0.00ad	27.40b	13.20bc	1.40cd	0.40d
		(0.00)	(0.00)	(15.02)	(7.26)	(0.93)	(0.40)
Burned Oak/ Sweetgum	Adults	2.00a	1.42a	0.33b	0.17c	0.00c	0.00c
		(0.75)	(0.53)	(0.14)	(0.17)	(0.00)	(0.00)
	Male	1.00a	0.83a	0.17b	0.17b	0.00b	0.00b
	(adult)	(0.35)	(0.34)	(0.11)	(0.17)	(0.00)	(0.00)
	Female	1.00a	0.58ab	0.17bc	0.00c	0.00c	0.00c
	(adult)	(0.44)	(0.29)	(0.11)	(0.00)	(0.00)	(0.00)
	Nymph	11.00a	5.08b	4.75b	1.17c	1.33c	0.00d
		(3.32)	(2.06)	(2.14)	(0.34)	(0.40)	(0.00)
	Larvae	0.00a	3.50a	15.67b	122.42b	13.50b	0.25a
		(0.00)	(2.44)	(7.37)	(69.27)	(7.51)	(0.13)

Table A-2. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Unburned Oak/ Sweetgum	Adults	0.88a (0.35)	0.56a (0.18)	0.06b (0.06)	0.00b (0.00)	0.00b (0.00)	0.00b (0.00)
	Male (adult)	0.38a (0.18)	0.50b (0.16)	0.06c (0.06)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Female (adult)	0.50a (0.22)	0.06b (0.06)	0.00b (0.00)	0.00b (0.00)	0.00b (0.00)	0.00b (0.00)
	Nymph	6.06a (1.56)	4.00b (1.11)	3.06b (0.98)	0.63c (0.26)	0.50c (0.20)	0.06d (0.06)
	Larvae	0.00a (0.00)	0.00a (0.00)	23.06b (15.79)	7.81c (6.63)	73.38d (49.08)	18.63d (13.43)
Sweetgum[1]	Adults	2.60a (0.93)	2.20a (0.86)	0.40b (0.24)	0.20bc (0.20)	0.00c (0.00)	0.00c (0.00)
	Male (adult)	0.60 (0.40)	0.40 (0.24)	0.20 (0.20)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Female (adult)	2.00a (0.84)	1.80a (0.73)	0.20b (0.20)	0.20b (0.20)	0.00b (0.00)	0.00b (0.00)
	Nymph	12.60a (2.23)	10.20a (2.35)	4.00b (1.64)	4.60b (0.60)	1.40c (0.93)	0.00d (0.00)
	Larvae	0.00a (0.00)	0.00a (0.00)	233.60b (160.02)	26.80c (24.32)	102.80b (82.84)	1.40c (0.68)

Table A-2. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Sweetgum/ Mixed	Adults	8.63a (5.27)	4.13a (1.46)	2.38a (0.84)	0.00b (0.00)	0.00b (0.00)	0.13b (0.13)
	Male (adult)	3.50ab (2.24)	2.00a (0.85)	0.63b (0.26)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Female (adult)	5.13a (3.04)	2.13a (0.77)	1.75a (0.70)	0.00b (0.00)	0.00b (0.00)	0.13b (0.13)
	Nymph	41.00a (28.81)	15.13a (2.46)	7.38b (1.08)	2.38c (0.84)	1.00d (0.73)	0.13d (0.13)
	Larvae	0.00a (0.00)	0.00a (0.00)	37.50bc (35.65)	0.13a (0.13)	53.88b (38.44)	2.00c (1.18)
Sweetgum/ Oak	Adults	2.00a (0.71)	1.80a (0.49)	1.20a (0.37)	0.00b (0.00)	0.00b (0.00)	0.20b (0.20)
	Male (adult)	1.60a (0.51)	1.00ab (0.32)	0.60b (0.24)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Female (adult)	0.40 (0.40)	0.80 (0.37)	0.60 (0.40)	0.00 (0.00)	0.00 (0.00)	0.20 (0.20)
	Nymph	17.60a (5.88)	18.20a (8.06)	7.80b (5.64)	5.40bc (4.43)	1.00cd (0.55)	0.20d (0.20)
	Larvae	0.00a (0.00)	0.00a (0.00)	202.20b (110.32)	0.40a (0.40)	210.20bc (198.27)	2.80c (0.80)

Table A-2. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Cedar	Adults	0.00a	1.60b	0.60b	0.00a	0.00a	0.00a
		(0.00)	(0.93)	(0.40)	(0.00)	(0.00)	(0.00)
	Male	0.00	0.60	0.20	0.00	0.00	0.00
	(adult)	(0.00)	(0.40)	(0.20)	(0.00)	(0.00)	(0.00)
	Female	0.00a	1.00b	0.40a	0.00a	0.00a	0.00a
	(adult)	(0.00)	(0.55)	(0.40)	(0.00)	(0.00)	(0.00)
	Nymph	4.40a	6.40a	1.60b	4.60a	1.20a	0.00c
		(0.60)	(1.60)	(0.51)	(1.29)	(0.58)	(0.00)
	Larvae	0.00a	0.00a	2.00bcd	5.20bd	2.00c	1.80d
		(0.00)	(0.00)	(0.84)	(2.31)	(1.38)	(0.58)
Mowed W/o trees	Adults	0.00	0.00	0.00	0.00	0.00	0.00
		(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Male	0.00	0.00	0.00	0.00	0.00	0.00
	(adult)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Female	0.00	0.00	0.00	0.00	0.00	0.00
	(adult)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Nymph	0.38a	0.00b	0.00b	0.38a	0.00b	0.00b
		(0.18)	(0.00)	(0.00)	(0.26)	(0.00)	(0.00)
	Larvae	0.00a	0.00a	0.00a	1.88b	0.00a	0.00a
		(0.00)	(0.00)	(0.00)	(1.13)	(0.00)	(0.00)

Table A-2. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Mowed w/trees	Adults	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Male (adult)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Female (adult)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Nymph	1.67a (1.30)	0.11b (0.11)	0.00b (0.00)	0.22b (0.15)	0.11b (0.11)	0.00b (0.00)
	Larvae	0.00a (0.00)	0.00a (0.00)	0.22a (0.22)	2.67b (1.45)	3.33b (1.96)	0.00a (0.00)
Tallgrass[1]	Adults	3.60a (1.49)	0.50b (0.22)	0.40bc (0.31)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Male (adult)	1.50a (0.52)	0.30b (0.15)	0.10bc (0.10)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Female (adult)	2.10a (1.11)	0.20b (0.20)	0.30b (0.21)	0.00b (0.00)	0.00b (0.00)	0.00b (0.00)
	Nymph	0.80ab (0.53)	1.10ac (0.46)	0.10bd (0.10)	2.20c (1.45)	3.20ac (2.76)	0.00d (0.00)
	Larvae	0.00a (0.00)	8.40a (8.40)	45.60b (12.64)	23.00c (12.53)	29.90d (19.62)	3.10d (1.21)

Table A-2. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
All vegetation types combined	Adults	2.27a (0.48)	1.50a (0.30)	0.62b (0.13)	0.08c (0.03)	0.01d (0.01)	0.02d (0.01)
	Males (adult)	1.12a (0.23)	0.76a (0.15)	0.28b (0.08)	0.02c (0.02)	0.00c (0.00)	0.00c (0.00)
	Females (adult)	1.15a (0.27)	0.74a (0.16)	0.34b (0.08)	0.06c (0.02)	0.01d (0.01)	0.02d (0.01)
	Nymphs	10.32a (2.40)	5.26b (0.70)	3.52b (0.57)	3.02b (0.55)	1.19c (0.28)	0.04d (0.02)
	Larvae	0.00a (0.00)	1.12a (0.79)	56.06b (13.93)	32.20b (9.61)	38.48b (12.65)	11.60c (5.55)

[1] Forested high visitor use areas.
[2] Lowercase letters that are the same within a row by lifestage indicate no difference (p-value ≥0.05).

Table A-3. Mean number of *Amblyomma americanum* ticks collected per 2m x 6m plot at Arkansas Post National Memorial, Arkansas County, Arkansas, 2000.

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Oak/Hickory[1]	Adults	1.13a[2]	0.75a	0.13b	0.25b	0.00b	0.00b
		(0.48)	(0.25)	(0.13)	(0.25)	(0.00)	(0.00)
	Males (adult)	0.50	0.38	0.13	0.13	0.00	0.00
		(0.38)	(0.18)	(0.13)	(0.13)	(0.00)	(0.00)
	Females (adult)	0.63	0.38	0.00	0.13	0.00	0.00
		(0.32)	(0.18)	(0.00)	(0.13)	(0.00)	(0.00)
	Nymphs	8.88a	3.63ac	1.88b	1.63c	0.38d	0.25d
		(5.79)	(1.74)	(1.09)	(0.32)	(0.18)	(0.25)
	Larvae	0.00a	0.00a	0.25a	14.75b	0.00a	6.13c
		(0.00)	(0.00)	(0.25)	(12.94)	(0.00)	(2.07)
Oak/Pine[1]	Adults	10.00a	9.68b	6.45b	2.18a	0.00c	0.00c
		(4.84)	(3.54)	(1.68)	(0.77)	(0.00)	(0.00)
	Males (adult)	4.68a	4.45a	3.00a	0.86b	0.00c	0.00c
		(2.01)	(1.70)	(0.92)	(0.27)	(0.00)	(0.00)
	Females (adult)	5.32a	5.23b	3.45b	1.32c	0.00d	0.00d
		(2.85)	(1.87)	(0.80)	(0.59)	(0.00)	(0.00)
	Nymphs	61.45a	33.82a	31.32a	35.23a	8.00b	1.14c
		(31.85)	(13.02)	(11.92)	(11.90)	(3.93)	(0.45)
	Larvae	9.05ad	0.00a	67.55b	134.77c	16.32d	33.77b
		(8.86)	(0.00)	(31.92)	(56.18)	(8.88)	(12.30)

Table A-3. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Oak/mixed spp.[1]	Adults	1.40a (0.24)	0.60b (0.40)	1.00b (0.45)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Males (adult)	1.40a (0.24)	0.40b (0.24)	0.20bc (0.20)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Females (adult)	0.00a (0.00)	0.20a (0.20)	0.80b (0.37)	0.00a (0.00)	0.00a (0.00)	0.00a (0.00)
	Nymphs	2.40ab (1.12)	3.00a (1.34)	1.00bc (0.45)	0.60cd (0.40)	0.20de (0.20)	0.00e (0.00)
	Larvae	0.00a (0.00)	0.00a (0.00)	35.00ac (35.00)	5.40bc (3.44)	59.40c (37.89)	37.40c (26.55)
Burned Oak/ Sweetgum	Adults	2.50a (1.22)	3.83b (1.25)	2.00ab (0.60)	0.67c (0.40)	0.00d (0.00)	0.00d (0.00)
	Males (adult)	1.25a (0.76)	1.75b (0.48)	0.67a (0.26)	0.17c (0.11)	0.00c (0.00)	0.00c (0.00)
	Females (adult)	1.25a (0.54)	2.08a (0.87)	1.33a (0.51)	0.50b (0.29)	0.00c (0.00)	0.00c (0.00)
	Nymphs	26.17a (18.52)	8.50ab (3.76)	9.00a (4.59)	6.33b (2.81)	0.67c (0.33)	0.17c (0.11)
	Larvae	0.00a (0.00)	16.67ab (16.58)	48.92bc (30.68)	99.50c (44.35)	5.00a (5.00)	6.67ab (4.66)

Table A-3. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Unburned Oak/ Sweetgum	Adults	3.06a (2.15)	1.81a (0.52)	0.44b (0.18)	0.63b (0.30)	0.00c (0.00)	0.00c (0.00)
	Males (adult)	1.38a (0.93)	0.94a (0.31)	0.00b (0.00)	0.19b (0.14)	0.00b (0.00)	0.00b (0.00)
	Females (adult)	1.69a (1.24)	0.88a (0.35)	0.44a (0.18)	0.44a (0.20)	0.00b (0.00)	0.00b (0.00)
	Nymphs	50.44a (45.85)	19.56a (10.09)	4.00a (1.39)	7.63a (4.13)	0.38b (0.13)	0.13b (0.09)
	Larvae	7.94ab (7.61)	0.00a (0.00)	0.63ab (0.46)	26.44b (19.53)	25.00b (21.98)	1.31ab (1.31)
Sweetgum[1]	Adults	4.20a (1.59)	2.60a (1.03)	0.60b (0.60)	0.20b (0.20)	0.00b (0.00)	0.00b (0.00)
	Males (adult)	2.40a (0.81)	1.60a (0.68)	0.00b (0.00)	0.20b (0.20)	0.00b (0.00)	0.00b (0.00)
	Females (adult)	1.80a (0.86)	1.00b (0.45)	0.60c (0.60)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Nymphs	9.00a (2.28)	4.20b (1.32)	5.60b (2.20)	3.80b (1.36)	0.80c (0.37)	0.20c (0.20)
	Larvae	4.40ac (4.40)	0.00a (0.00)	26.60acd (21.73)	343.80b (111.74)	107.20cd (66.85)	114.00d (67.03)

Table A-3. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Sweetgum/ Mixed	Adults	0.88a (0.30)	1.38a (0.53)	0.88a (0.35)	0.75a (0.25)	0.00b (0.00)	0.00b (0.00)
	Males (adult)	0.38 (0.18)	0.25 (0.25)	0.50 (0.27)	0.13 (0.13)	0.00 (0.00)	0.00 (0.00)
	Females (adult)	0.50a (0.27)	1.13b (0.40)	0.38a (0.18)	0.63ab (0.26)	0.00c (0.00)	0.00c (0.00)
	Nymphs	5.50a (1.65)	8.50b (2.04)	8.25b (1.75)	10.38b (2.99)	1.13c (0.48)	0.25c (0.16)
	Larvae	0.00 (0.00)	0.00 (0.00)	10.50 (10.36)	2.25 (2.25)	0.00 (0.00)	3.13 (3.13)
Sweetgum/ Oak	Adults	0.00a (0.00)	0.60b (0.40)	1.00b (0.77)	0.40ab (0.40)	0.00a (0.00)	0.00a (0.00)
	Males (adult)	0.00 (0.00)	0.20 (0.20)	0.80 (0.58)	0.20 (0.20)	0.00 (0.00)	0.00 (0.00)
	Females (adult)	0.00 (0.00)	0.40 (0.24)	0.20 (0.20)	0.20 (0.20)	0.00 (0.00)	0.00 (0.00)
	Nymphs	4.80a (2.82)	1.60b (0.51)	6.60c (3.14)	4.40ac (1.57)	0.80d (0.58)	0.60d (0.40)
	Larvae	12.60a (12.60)	0.00a (0.00)	32.20a (32.20)	9.20a (9.20)	152.40b (106.92)	30.60a (30.60)

Table A-3. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Cedar	Adults	0.00ac	0.40abc	0.60b	0.00c	0.00c	0.00c
		(0.00)	(0.40)	(0.40)	(0.00)	(0.00)	(0.00)
	Males	0.00	0.20	0.40	0.00	0.00	0.00
	(adult)	(0.00)	(0.20)	(0.40)	(0.00)	(0.00)	(0.00)
	Females	0.00	0.20	0.20	0.00	0.00	0.00
	(adult)	(0.00)	(0.20)	(0.20)	(0.00)	(0.00)	(0.00)
	Nymphs	0.80a	3.60b	3.20bc	2.40c	0.60a	0.60a
		(0.58)	(0.60)	(1.02)	(0.81)	(0.40)	(0.40)
	Larvae	0.00a	0.00a	0.00a	0.00a	107.00b	103.40c
		(0.00)	(0.00)	(0.00)	(0.00)	(82.30)	(37.18)
Mowed W/o trees	Adults	0.50a	0.00b	0.00b	0.00b	0.00b	0.00b
		(0.27)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Males	0.38	0.00	0.00	0.00	0.00	0.00
	(adult)	(0.26)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Females	0.13	0.00	0.00	0.00	0.00	0.00
	(adult)	(0.13)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
	Nymphs	2.63a	0.25ab	0.00b	0.00b	0.00b	0.00b
		(2.21)	(0.16)	(0.00)	(0.00)	(0.00)	(0.00)
	Larvae	0.00	0.25	0.00	0.00	0.00	0.00
		(0.00)	(0.16)	(0.00)	(0.00)	(0.00)	(0.00)

Table A-3. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
Mowed w/trees	Adults	0.22 (0.15)	0.11 (0.11)	0.11 (0.11)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Males (adult)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Females (adult)	0.22 (0.15)	0.11 (0.11)	0.11 (0.11)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	Nymphs	2.22a (1.18)	0.78a (0.43)	0.11b (0.11)	0.00b (0.00)	0.00b (0.00)	0.00b (0.00)
	Larvae	0.11 (0.11)	0.22 (0.22)	0.22 (0.22)	0.44 (0.34)	0.00 (0.00)	0.00 (0.00)
Tallgrass[1]	Adults	3.40a (1.18)	1.40b (0.67)	0.70bc (0.42)	0.10cd (0.10)	0.00d (0.00)	0.00d (0.00)
	Males (adult)	2.70a (1.01)	0.60b (0.27)	0.40bc (0.27)	0.00c (0.00)	0.00c (0.00)	0.00c (0.00)
	Females (adult)	0.70a (0.30)	0.80ab (0.47)	0.30bc (0.21)	0.10c (0.10)	0.00c (0.00)	0.00c (0.00)
	Nymphs	12.50a (6.63)	6.00a (2.43)	2.50b (1.25)	1.00bc (0.45)	0.50c (0.22)	0.50c (0.22)
	Larvaes	0.80a (0.51)	0.00b (0.00)	254.60c (179.78)	34.30a (21.44)	0.00b (0.00)	10.60ab (10.60)

Table A-3. Continued

Vegetation type	Lifestage	May	June	July	Aug.	Sept.	Oct.
All vegetation types combined	Adults	3.39a (1.04)	3.02a (0.77)	1.81a (0.40)	0.69b (0.18)	0.00c (0.00)	0.00c (0.00)
	Males (adult)	1.73a (0.45)	1.39a (0.37)	0.80b (0.21)	0.25c (0.06)	0.00d (0.00)	0.00d (0.00)
	Females (adult)	1.65a (0.60)	1.63a (0.41)	1.02a (0.21)	0.44b (0.13)	0.00c (0.00)	0.00c (0.00)
	Nymphs	25.12a (9.28)	12.27ab (3.11)	9.29bc (2.57)	10.04c (2.66)	1.94d (0.80)	0.40e (0.10)
	Larvae	3.72a (2.10)	1.81a (1.76)	45.89b (18.04)	60.68b (14.96)	26.10b (8.08)	21.69b (5.17)

[1] Forested high visitor use areas.

[2] Lowercase letters that are the same within a row by lifestage indicate no difference (p-value ≥0.05).